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The Convergence Behavior of CO_2 Emissions in Seven Regions under Multiple Structural Breaks

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ABSTRACT

The aim of this paper is to examine the convergence behavior of carbon dioxide emissions per capita (*co*) in seven regions for 1960-2011 period by using recently developed the second generation panel data methods. Empirical results are as follows: (i) There exists cross-sectional dependency for *co* variable, (ii) the cross-sectionally augmented Dickey Fuller unit root test without structural breaks shows that the *co* variable is stationary at its first differences, (iii) but the panel KPSS unit root test with structural breaks the *co* variable is stationary at its level. The overall results indicate that the regional stochastic convergence of carbon emission per capita is valid for the seven regions under structural breaks and any environmental shock has temporary effect.

Keywords: Carbon Emissions, Stochastic Convergence, Panel Data
JEL Classifications: C33, Q53, Q56

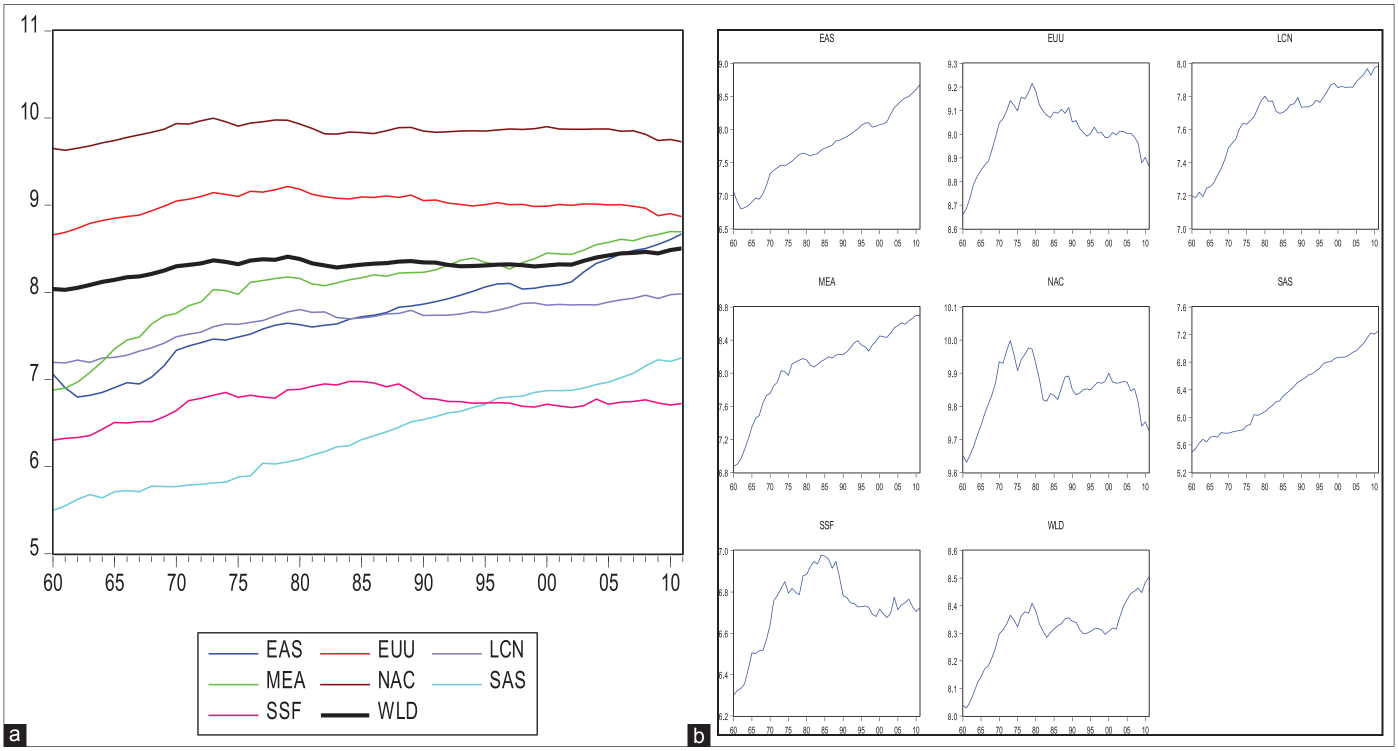
1. INTRODUCTION

The challenge of convergence in carbon emission has a broad repercussion in economic literature due to global warming phenomenon. Herein, carbon emission is considered as main reason of global warming and climate change. Despite the developed countries are most pollutant due to their dependence on carbon-based energy sources, environmental problems are considered as not only belong to developed countries, but also belong to developing countries owing to its global effects. This situation has brought an international aspect to environmental problems. In this context, Stockholm Conference which held on 1972 by United Nations was the first international initiative on environmental problems. In a half a century which has taken a place since Stockholm Conference, main concern of governments has been the reducing and stabilizing of environmental pollution. Therefore, understanding of the course of carbon emission is become a vital issue for policy makers to reduce greenhouse gasses to prevent global warming. Furthermore, many economists have been motivated to disclose environmental consequences of economic growth. Convergence approach has been an alternative way for measuring the success of reducing policies towards to carbon emission. This approach that originally belongs to economic growth theory has led to large body of empirical researches by economists.

Figure 1 presents carbon emissions per capita for world and seven regions. Obviously, carbon emissions per capita for middle-east and North Africa, South Asia, Latin America and Caribbean and East Asia and Pacific at Figure 1a are also moving with an upward trend and closing to World's level. On the contrary, European Union and North America's carbon emissions are moving with a downward trend and also closing to World's level. Finally, carbon emissions per capita for Sub-Saharan Africa is fluctuating below World's level. On the other hand, Figure 1b indicates that carbon emission per capita series for most regions have some structural changes and econometric analysis should take into account this problem.

Since the seminal work of Strazicich and List's (2003), the convergence behavior of carbon dioxide emissions becomes a popular research area in the empirical literature. They found notion of convergence in 21 industrialized countries for the period of 1960-1997 by using panel unit root and cross-section regression

Figure 1: Carbon emissions per capita for world and regions, EAS: East Asia and Pacific, EUU: European Union, LCN: Latin America and Caribbean, MEA: Middle East and North Africa, NAC: North America, SAS: South Asia, SSF: Sub-Saharan Africa, WLD: World



methods. Subsequently, some researchers as Aldy (2006) and Barassi et al. (2008) have found proof of divergence for some countries. Table 1 presents empirical studies on convergence of carbon dioxide emissions. The most of these studies applied the first generation panel methods for different countries and time periods. Generally, these models are assumed that there is cross-section independency between error terms in panel data models. Pesaran (2004) argued that the panel data with number of large cross-sections, yet in case that the panel data with smaller N and relatively large T dimension, cross-section dependence can occur.

However, the literature on panel data analysis emphasized that cross-section dependence, the interaction between cross-sectional units, can arise due to a variety of factors, such as omitted observed common factors and unobserved common factors, spatial spillover effects or general residual interdependence. In the presence of cross-sectional dependence, the first generation panel data methods may lead to biased inferences and hence misleading results due to lower power of the unit root and cointegration test (Pesaran, 2004; Breitung and Pesaran, 2008; Baltagi et al., 2012; Westerlund and Breitung, 2013).

Therefore, this study aims to contribute to existed convergence literature through exploring the stochastic convergence of carbon emissions per capita in seven regions of the world for 1960-2011 period. Although the panel unit root test has a convenient methodology to detect the validity of stochastic convergence hypothesis, this study employs two recently developed panel unit root tests that have more efficient estimators under the existence of cross-section dependence in the data. The first test is the cross-sectionally augmented Dickey Fuller (hereafter, CADF) test developed by Pesaran (2007) and the second test is the panel KPSS (hereafter, PANKPSS) test proposed by Carion-i Silvestre et al. (2005). The CADF test assumes no structural breaks and may has lack power for carbon emissions per capita series that are stationary around a breaking trend. But, Figure 1b indicate that there exist several breaks at carbon emissions per capita series for regions. Therefore, this paper applies the PANKPSS unit root test to deal with this problem.

The rest of paper is organized as follows: (i) The Section 2 introduces model, data and methodology, (ii) the Section 3 reports the empirical results, (iii) the Section 4 concludes the paper.

2. MODEL, DATA AND METHODOLOGY

2.1. Model and Data

This study employs Evans' (1998) approach which refers that the long-run carbon emissions gap between any two regions must be stationary. Firstly, He starts to work by assuming hypotheses as follows:

H_0: For a positive fraction of regions indexed by n, y_{nt}, is not cointegrated with the y_s of the other regions and the mean of Δy_{nt} differs from the means of all other $\Delta y's$.

H_1: For every pair of regions n and m, $y_{nt}-y_{mt}$ is stationary and may have nonzero mean.

Null and alternative hypotheses can be tested by estimating the equation as follows:

$$\Delta(y_{nt}-\bar{y}_t)=\gamma_n+\rho_n(y_{n,t-1}-\bar{y}_{t-1})+\sum_{i=1}^{p}\varphi_{ni}\Delta(y_{n,t-i}-\bar{y}_{t-i})+u_{nt} \quad (1)$$

Table 1: Literature table

Author (s)	Sample-period	Method	Result
Strazicich and List (2003)	21 industrial countries 1960-1997	Panel unit root test and cross-section regression	Convergence
Nguyen-Van (2005)	100 countries 1966-1996	Non-parametric approach/Arellano and bond dynamic panel approach	Convergence
Aldy (2006)	23 OECD countries 1960-2000 88 countries 1960-2000	ADF unit root test	Convergence for 20 countries Convergence for 75 countries
Ezcurra (2007)	87 countries 1960-1999	Non-parametric approach/method	Convergence
Westerlund and Basher (2008)	16 developed countries 1870-2002 12 developing countries 1901-2002	Panel unit root test	Convergence Convergence
Barassi et al. (2008)	21 OECD countries 1950-2002	Time series and panel unit root test	Divergence
Chiang Lee and Ping (2008)	21 OECD countries 1960-2000	SURADF panel unit root test	Convergence for 7 countries Divergence for 14 Countries
Romero-Avila (2008)	23 countries 1960-2002	Panel unit root test	Convergence
Aslan (2009)	1950-2004	Panel unit root test	Divergence
Chiang Lee and Ping (2009)	21 OECD countries 1950-2002	Panel unit root test	Convergence
Bimonte (2009)	19 OECD countries 1970-2006	Cross-sectional and time series tests	Convergence
Jobert et al. (2010)	22 European Union Countries 1971-2006	Bayesian regression	Convergence
Criado and Grether (2011)	166 world areas 1960-2002	Non-parametric distributional tests	Convergence for clubs Divergence for whole
Herrerias (2012)	EU-25 countries 1920-2007	Distribution dynamics approach	Convergence
Herrerias (2013)	Developed and developing countries 1980-2009	Panel unit root test	Convergence for large of group Divergence for some of group Divergence according to source of energy
Li and Lin (2013)	110 countries 1971-2008	Panel data analysis	Convergence
Lin Li et al. (2014)	50 States of U.S.A 1990-2010	Sequential panel selection method and KPSS unit root tests	Convergence for 12 States Divergence for 38 States
Wang et al. (2014)	Provinces of China 1995-2011	The log t-test method	Convergence for Clubs Divergence for Country as a Whole
Hao et al. (2015)	29 Provinces of China 1995-2011	Panel unit root tests	Convergence

$n = 1,2,\dots N$ and $t = 1,2,\dots,T$

$\bar{y}_t$ could be expressed as below:

$$\bar{y}_t \equiv (1/N)\sum_{n=1}^{N} y_{nt} \quad (2)$$

Where, γ_n, ρ_n and $\varphi' s$ represent parameters, p is some sufficiently large integer and u_{nt} represents a serially uncorrelated error term with zero mean and finite variance σ_n^2.

Consequently, panel data unit root test has been employed for testing stationary property of carbon emissions per capita series. To shape this idea empirically, presume that y_{it} is natural logarithmic carbon emissions, for cross-sections $i = 1,\dots N$ at time $t = 1,\dots,T$ is non-stationary, so present a unit root. In order to examine carbon emissions per capita convergence among seven regions, this study uses the annual data for carbon emissions per capita (CO_2 metric kilograms per capita) for 1960-2011 period. Moreover, data for carbon emissions per capita have been taken from the world development indicators online database and then linearized by taking natural logarithms.

2.2. Testing the Cross-sectional Dependency

This paper first aims to examine whether the variables are cross-sectional dependence or independence using the approaches developed by Breusch and Pagan (1980) and Pesaran et al. (2008). Breusch and Pagan propose following cross-section dependence test which based on Lagrange multiplier:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(\hat{p}_{ij}^2) \sim \frac{X^2 N(N-1)}{2} \quad (3)$$

Where, $(\hat{p}_{ij}^2)$ is the correlation coefficient of residuals. Lagrange multiplier test has good properties for large T and small N. Pesaran et al. (2008) propose following cross-section dependence test which is adjusted form of Breusch-Pagan's LM statics that is called as "Bias-adjusted LM test:"

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{p}_{ij}^2 - \mu_{Tij}}{\upsilon_{Tij}} \quad (4)$$

Bias-adjusted LM test has good properties when $T > N$ or $T < N$. Besides, possible biases are adjusted when N is larger than T. Both tests work under the null hypothesis of no cross-sectional dependency.

2.3. Stationarity Analysis

In this study, stationary property of series has been tested by two recently developed panel unit root tests which are the CADF and the PANKPSS tests. The CADF panel unit root test developed by Pesaran (2007).

Let y_{it} be the observation on the i^{th} cross-section unit at time t and suppose that it is generated according to the simple dynamic linear heterogeneous panel data model:

$y_{it} = (1-\phi_i)\mu_i + \phi_i y_{i,t-1} + u_{it}$, where, $i = 1,2,\ldots,N$ and $t = 1,2,\ldots,T$ (5)

Where, initial value, y_{i0}, has a given density function with a finite mean and variance, and the error term, u_{it}, has the single-factor structure.

$$u_{it} = \gamma_i + f_t + \varepsilon_{it} \quad (6)$$

In which f_t is the unobserved common effect, and ε_{it} is the individual-specific (idiosyncratic) error. It is convenient to write (5) and (6) as:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \quad (7)$$

The unit root hypothesis of interest $\phi_i = 1$, can now be expressed as:

$$H_0: \beta_i = 0 \text{ for all } i \quad (8)$$

Against the possibly heterogeneous alternatives,

$$H_0: \beta_i < 0,\ i = 1,2,\ldots N_1,\ \beta_i = 0,\ i = N_1+1, N_1+2,\ldots N \quad (9)$$

Under the null hypothesis of unit root, the cross-sectionally augmented IPS (CIPS) test depends on the simple average of the individual ($CADF_i$) statistics. It is defined by:

$$CIPS = \sum_{i=1}^{N} \frac{CADF_i}{N} \quad (10)$$

However, the individual CADFs and the corresponding CIPS panel statistic CIPS have non-normal distributions, so their critical values for different N and T are obtained by Monte Carlo simulations. Pesaran (2007) gives critical values of CIPS in Table 2.

Carion-i Silvestre et al. panel unit root test considers multiple breaks as well as breaks in time trends and averages of series which form panel data. This method allows different numbers of structural breaks in different dates for each cross-section. The PANKPSS test is based on Hadri (2000) methods and tests stationarity property of panel under the null hypothesis of stationary. Besides, this method allows to test stationarity of panel or individual cross-sections.

Model could be expressed as below:

$$y_{it} = \alpha_{it} + \beta_{it} + \varepsilon_{it} \quad i = 1,2,\ldots N \text{ and } t = 1,2,\ldots T \quad (11)$$

α_{it} could be expressed as below:

$$\beta_{it} = \sum_{k=1}^{m_i} \theta_{i,k} D(T_{b,k}^i)_t + \sum_{k=1}^{m_i} \gamma_{i,k} DU_{i,kt} + \alpha_{i,t-1} + u_{it} \quad (12)$$

u_{it} could be expressed as $u_{it} \sim i.i.d(0,\sigma_{u,i}^2)$ and $a_{i0} = a_i$; let it to be constant. Dummy variables of equations for cross-section of i and break date of k which stated as above could be expressed as:

$D(T_{b,k}^i)_t = 1$ for $t = T_{b,k}^i + 1$ and 0 elsewhere,

$DU_{i,k,t} = 1$ for $t > T_{b,k}^i$ and 0 elsewhere.

Table 2: Cross-sectional dependency tests results

Tests	co
CD LM1 (Breusch-Pagan 1980)	66.041 (0.000)
Bias-adjusted CD test	8.760 (0.000)

In model, let the k to be as $k = 1,2,\ldots m$. As it could be seen here, model allows number of m breaks. Null hypothesis of model could be expressed as below:

$$H_0: \sigma_{u,i}^2 = 0 \quad (i = 1,2,\ldots,N)$$

Equation 4 can be rearranged as below by considering null hypothesis:

$$y_{i,t} = a_i + \sum_{k=1}^{m_i} \theta_{i,k} DU_{i,k,t} + \beta_{i,t} + \sum_{k=1}^{m_i} \gamma_{i,k} DT_{i,k,t}^* + \varepsilon_{i,t} \quad (13)$$

($DT_{i,k,t}^* = t - T_{b,k}^i$ for $t > T_{b,k}^i$ and 0 elsewhere).

Null hypothesis can be tested as below through LM_{hom} statics by presuming long-run variance changes between cross sections:

$$LM_{het}(\lambda) = N^{-1} \sum_{i=1}^{N} (\hat{\omega}^{-2} T^{-2} \sum_{t=1}^{T} \hat{S}_{i,t}^2) \quad (14)$$

And $\hat{S}_{it}$ could be expressed as $\hat{S}_{it} = \sum_{j=1}^{t} u_{ij}$, while $\hat{\omega}_i^2$ could be expressed as $N^{-1} \sum_{i=1}^{N} \hat{\omega}^2$ and $\hat{\omega}_i^2 = \lim T^{-1} S_{i,T}^2$.

($\varepsilon_{i,t}$) denotes ordinary least squares residuals and ($\hat{\omega}_i^2$) denotes consistent estimator of long-run variance of (ε_{it}). (λ) denotes that test statics depends on structural break dates. Null hypothesis $H_0: \sigma_{u,i}^2 = 0$ ($i = 1,2,\ldots N$) can be tested as below through LM_{hom} statics by presuming long-run variance is fixed:

$$LM_{\text{hom}}(\lambda) = N^{-1} \sum_{i=1}^{N} (\hat{\omega}^{-2} T^{-2} \sum_{t=1}^{T} \hat{S}_{i,t}^2) \quad (15)$$

LM statistics is normalized as follows:

$$Z(\lambda) = \frac{\sqrt{N}(LM(\lambda) - \bar{\xi})}{\bar{\varsigma}} \sim N(0,1) \quad (16)$$

$\bar{\xi}$ and $\bar{\varsigma}$ denote expected value and arithmetic mean of variances for each cross-sections.

3. EMPIRICAL RESULTS

3.1. Cross-sectional Dependence Tests Results

The cross-sectional dependency test result at Table 2 presents that the null hypothesis of no cross-sectional dependence is rejected at 1^ significance level. This implies that any shock at carbon emissions per capita (hereafter, *co*) occurs in any region affects another's.

3.2. Panel Unit Root Tests Results

Although there exists cross-sectional dependence, this study employs recently developed the CADF and PANKSS panel unit root tests. Table 3 reports the CADF and CIPS tests results that the null hypothesis of non-stationarity is accepted for five regions but is rejected for two regions. While *co* variable for the most of regions are nonstationary at their levels but they are stationary for all regions at their first differences. Unlike some CADF statics, the CIPS statistics for whole panel indicates that the null hypothesis of non-stationarity is accepted at their levels but is rejected at their first differences for all significance levels. While implementing of heterogeneous panel data unit root test, panel results mustn't contradict with individual test results. Rejection of null hypothesis even in one individual series can cause biased test results while accepting of null hypothesis for whole panel (Guloglu and Ispir, 2011). This result means that the *co* variable for all regions is nonstationary and the stochastic convergence hypothesis is not valid under the CIPS unit root test without structural breaks.

Although the CADF unit root test assumes any structural breaks and may has lack power for series that are stationary around a breaking trend. Therefore, stationarity properties of series have been tested through considering structural breaks by implementing Carion-i Silvestre et al. PANKPSS test. Table 4 shows that the null hypothesis of stationarity is accepted for both of all regions and whole panel at all significance levels under the both assumption of heterogeneity and homogeneity of long-run variance. Because of presence of cross-sectional dependence, bootstrap critical values are employed the instead of asymptotic critical values. Unlike the CIPS unit root test result, the PANKPSS test result indicates that the *co* variables for all regions are stationary and stochastic convergence hypothesis is valid under structural breaks. This shows that any environmental shock has temporary effect on carbon emissions per capita in seven regions.

Table 3: CIPS unit root test results

Regions	Constant and trend	First difference
co	CADF-stat	CADF-stat
EAS	−2.983	−5.132
EUU	−1.582	−4.713
LCN	−3.418	−5.119
MEA	−2.731	−4.307
NAC	−1.518	−4.045
SAS	−2.208	−5.571
SSF	−2.407	−3.571
CIPS-Stat	−2.407	−4.637
Critical	1%-3.040	1%-2.540
values	5%-2.830	5%-2.330
	10%-2.720	10%-2.210

Maximum lag-length has been determined as K=1 according to SIC. Critical values have been obtained from Pesaran's (2007. p. 279-280-281), EAS: East Asia and Pacific, EUU: European Union, LCN: Latin America and Caribbean, MEA: Middle East and North Africa, NAC: North America, SAS: South Asia, SSF: Sub-Saharan Africa, SIC: Schwarz-Bayesian information criteria, CADF: Cross-sectionally augmented Dickey Fuller, CIPS: Cross-sectionally augmented IPS

Table 4: Carrion-i-Silvestre et al. unit root test results

co	Level and trend shift model: Breaks in constant and trend							
	Panel KPSS	Bootstrap critical values 10%	5%	1%	M	T_{B1}	T_{B2}	T_{B3}
EAS	0.076	0.104	0.133	0.197	2.000	1968	1997	
EUU	0.026	0.125	0.163	0.236	3.000	1973	1980	2002
LCN	0.031	0.106	0.141	0.213	2.000	1969	1982	
MEA	0.058	0.138	0.174	0.256	3.000	1971	1980	1995
NAC	0.026	0.118	0.151	0.228	3.000	1973	1980	2004
SAS	0.044	0.102	0.132	0.199	2.000	1976	2000	
SSF	0.023	0.132	0.172	0.241	3.000	1970	1985	1992
Panel^A	4.794	15.933	18.501	23.374				
Panel^B	6.126	10.395	11.908	15.606				

Panel KPSS test denotes individual KPSS test with multiple structural breaks. M is the number of structural breaks and is selected using the LWZ criterion. TB is the dates of structural breaks. ^{A}Test statistic is computed under the heterogeneity of long run variance assumption, ^{B}Test statistic is computed under the homogeneity of long run variance assumption. The long-run variance was estimated using Barlett kernel with automatic spectral window bandwidth selection. Bootstrap critical values are based on 5000 bootstrap replications. EAS: East Asia and Pacific, EUU: European Union, LCN: Latin America and Caribbean, MEA: Middle East and North Africa, NAC: North America, SAS: South Asia, SSF: Sub-Saharan Africa

4. CONCLUSIONS

Since the seminal work of Strazicich and List's (2003), the convergence behavior of carbon dioxide emissions becomes a popular research area in the empirical literature. Most of studies employed either time series methods with low power, or the first generation panel methods assume cross-sectional independence. Differently, this study try to explore the stochastic convergence of carbon emissions per capita in seven regions of the world for 1960-2011 period by using two recently developed second generation panel unit root tests. The CADF test allows no structural breaks and may has lack power for carbon emissions per capita series that are stationary around a breaking trend. Although carbon emissions per capita series for regions have several breaks, this paper also applies the PANKPSS unit root test to deal with this problem.

Empirical results are as follows: (i) There exists cross-sectional dependency for carbon emission per capita (*co*) variable, (ii) the CADF unit root test shows that the *co* variable is stationary at its first differences, its means that carbon emissions have diverged, and (iii) but the PANKPSS unit root test with structural breaks presents that the *co* variable is stationary at its level. Last result refers that the *co* variable is stationary around structural breaks. The overall results indicate that the regional convergence of carbon emission per capita is valid for the seven regions and any environmental shock has temporary effect. This result is consonant with the studies as Strazicich and List (2003) and Westerlund and Basher (2008).

The existence of convergence notion for seven regions of world can make it easier for not only developed countries and but also developing countries to deal with carbon and greenhouse gasses reduction protocols as Kyoto. Furthermore, it can help to taking of precautions to curb global warming and climate changes. International cooperation on environmental problems and energy saving policies may support the controlling carbon emissions and protect the environment from climate change in the long run.

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