Per Capita Carbon Dioxide Emission in the Developing Economies: Convergence or Divergence?

Siti Ayu Jalil

Faculty of Business and Management, Universiti Teknologi MARA, Selangor, Malaysia

***Abstract* — This study analyzes the convergence of per capita carbon dioxide emission for 126 developing countries situated in Africa, Latin America and the Caribbean, Middle East and North Africa, as well as Asia and the Pacific regions from 1971 to 2009. It employs the current technique proposed by Phillips and Sul (2007) also known as the log-t test. This method is crucial due to its ability to determine the possibility of club convergence that may arise if result shows a divergent pattern. The analysis is significant in order to propose climate change proposals besides being an incentive for developing countries to participate seriously in controlling their emission level. Empirical evidence shows the developing countries portray a convergent pattern of per capita carbon dioxide emissions.**

Keywords - *Carbon Dioxide (CO_2), developing economies, convergence, divergence, log-t test*

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I. Introduction

Developing countries predicted to be the next largest emitters of carbon dioxide emissions has become the central focus mainly because they are still in their developing needs. Majority of these nations belong to the low-income and lower-middle income groups though a number of them are categorized as upper-middle income and high-income economies.[1] Since economic growth plays a critical role in these countries which are striving to be among the high-income economies, they are thus reluctant to make any commitments under the Kyoto Protocol as they oppose any measures to reduce greenhouse gas emissions that might constrain their economic development (Mielnik and Goldemberg, 2000). Understanding the needs of developing countries, and their commitment towards their social and economic development goals, the Kyoto Protocol has somehow adopted a principle of "common but differentiated responsibilities". Under this principle, the parties agreed that the per capita emissions and the share of emissions of developing countries were still relatively low and thus would be allowed to grow so as to meet their social and economic development needs (UNFCCC, 2006). However, this does not mean that the developing countries should not be responsible for their actions as any effects of climate change will likely be most felt by these countries, the very countries that are least prepared to deal with them.

The developing countries were found to constitute 50 percent of the top thirty emitters with China and India being the top two largest emitters followed by South Korea, Iran and Mexico. It is also interesting to note that three ASEAN[2] members, Indonesia, Thailand and Malaysia are listed among the top thirty emitters. According

[1] See Appendix for the list of countries in each income group.
[2] Association of the South East Asian Nation (ASEAN).

to the International Energy Agency (IEA) 2010 report the developing countries showed a glaring increase of CO_2 emissions by 6 percent compared with developed countries that dropped by 2 percent. CO_2 emissions had increased significantly in China (8 percent), the Middle East (7 percent), other Asian countries (4 percent) and Latin America (4 percent). Furthermore, fossil fuels, especially coal, are recognized to be the major source of energy supply in the developing countries apart from oil and natural gas. Hence a matter of concern is their ability to take effective action in relation to climate change due to their heavy dependency on fossil and solid fuels like wood that contribute to large carbon emissions (Han and Chatterjee, 1997).

The existence of cross-country studies on CO_2 emission convergence is quite recent and has become a popular interest to policymakers in preparing climate change policy proposals. The question arises on whether convergence of CO_2 emissions could occur similar to income and hence could be thought to be a part of economic growth. Convergence in relative CO_2 emissions implies that countries are not following independent paths in pollution control, but are collectively moving towards a common standard of environmental performance (Lee and Chang, 2008). If this holds true then, it becomes clear that global CO_2 emissions should be reduced significantly and per capita emissions should gradually move toward further convergence (Bohringer and Welsch, 2004). Hence the focus on examining the existence of convergence of CO_2 emissions among developing countries is essential so as to clarify whether a common energy and environmental policy is reasonable to be applied to these countries. When there is such evidence then it would be proper for policymakers to suggest appropriate measures, which cater to the whole developing region or a particular region or even perhaps nations.

Various empirical studies investigated on per capita CO_2 emissions convergence employ different econometric techniques give more attention to the developed nations such as the OECD countries and European Union (EU) members. However, the theory of CO_2 emission convergence among the developing countries is still relatively new. Therefore, it is essential to investigate these developing regions as Aldy (2006) states, the importance of understanding and considering the distribution of per capita CO_2 emissions is crucial in designing international climate change proposals and incentives for participation. In other words, if there is lack of emissions convergence among the developing countries may cause them less likely to agree to the emissions abatement obligations. He also emphasized further per capita carbon dioxide emissions scheme is more appropriate to measure since it reflects the variations in economic development, climate and policies for land use, energy and the environment. Consequently, the study attempts to fill this gap by scrutinizing a detailed investigation on convergence of per capita CO_2 emission among the developing countries. It will be very interesting for the developing nations being the future potential larger emitters participate actively in multilateral climate change agreements to be able to negotiate and establish their emission goals and commitments in the future.

The main objective of this study is to utilize the recent technique of convergence model proposed by Phillips and Sul (2007) popularly known as the log-*t* test. The model can identify the existence of convergence and determine the pattern of per capita CO_2 emissions from 1971 to 2009. Interestingly this method may also clarify the existence of whether an unconditional (absolute) or a conditional converging economy for the whole panel within the four regions. The rest of the paper is organized as follows. Section 2 briefly reviews the empirical literature whilst Section 3 describes a detailed methodology for conducting the analysis including as well the sources of data. Section 4 discusses the main empirical findings while Section 5 concludes the study.

II. Literature Review

According to Bohringer and Welsch (2004), in the context of climate protection policy, it has been suggested that global CO_2 emissions should be reduced significantly and that per capita emissions should be gradually equalized across countries (convergence). Convergence in relative CO_2 emissions, as explained by Lee and Chang (2008), implies that countries are not following independent paths in pollution control, but are collectively moving towards a common standard of environmental performance. Furthermore, Romero-Avila (2008) mentioned that if convergence in per capita emissions was achieved in developed countries, this would encourage the developing countries to accept a cap on their own emissions. As Aldy (2006) stated, the importance of understanding and considering the distribution of per capita CO_2 emissions is crucial in designing international climate change proposals and incentives for participation.

Various empirical studies on per capita CO_2 emissions convergence employing different econometric techniques for different countries gave more attention to developed nations such as the Organization for Economic Cooperation and Development (OECD) countries and European Union (EU) members, which are historically active emitters. For example, Strazicich and List (2003) examined whether emissions converged among 21 industrial countries using cross-sectional regression tests and panel unit root test (Im, Pesaran and Shin, 2003). The results found significant evidence of per capita CO_2 emissions convergence. Aldy (2006) further confirmed the convergence hypothesis among 23 OECD member countries when testing using the unit roots, however when applied to a global sample of 88 countries the emissions appeared to be diverging. The studies on developed nations seem to provide similar result, that is per capita CO_2 emissions converge even though the econometric methods utilized differ, for example the studies by Nguyen-Van (2005) and Romero-Avila (2008) which employed nonparametric and new version of panel stationarity tests respectively. The Nguyen-Van results differ when tested on 100 countries sample where it is stated that there is 'little evidence of convergence'. Lee, Chang and Chen (2008) applied unit root structural break tests for 21 OECD countries, found that per capita CO_2 emissions stochastically converged, consistent with the abovementioned studies. A recent study by Jobert, Karanfil and Tykhonenko (2010) on 22 European countries found similar evidence although the countries differ in emissions trend, convergence speed and their industry share of GDP.

Surprisingly when Lee and Chang (2008) did a study using seemingly unrelated regressions augmented Dickey-Fuller tests on 21 OECD countries, they estimated that only 7 countries showed convergence of per capita CO_2 emissions. Barassi, Cole and Elliot (2008) who re-examined the time-series literature on the convergence of per capita CO_2 emissions on 21 OECD countries employing panel unit root tests allowing for cross-sectional dependencies, obtained results that suggest no per capita CO_2 emissions convergence among these nations, thus contradicting previous results. It is rather interesting that when Westerlund and Basher (2008) studied a century of panel data covering the periods1870-2002 for 16 developed countries, and 1901 to 2002 for 12 developing countries using the same hypothesis of panel convergence tests their results showed a convergence in per capita CO_2 emissions. They also reported the speed of convergence to be half-life of about five years for both developed and developing countries.

The next discussion on empirical studies on per capita CO_2 emissions convergence looks at a global perspective, meaning large samples of countries. Ezcurra (2007) examined the spatial distribution of per capita CO_2 emissions in 87 countries using a nonparametric approach. His results revealed a decline in cross-country disparities in per capita CO_2 emissions which decreased throughout the 40-year period. In contrast Panopoulou and Pantelidis (2009) tested the existence of convergence clubs (i.e. identify groups of countries converging to different equilibria) among 128 countries based on a new methodology introduced by Phillips and Sul (2007). Their results suggested that convergence existed in the early years of the sample while in more recent years two convergence clubs were detected, one comprised countries with high per capita CO_2 emissions and the other with low per capita CO_2 emissions. An interesting finding is the evidence of transitioning between the two convergent clubs, either a slow convergence between the two clubs or a tendency for some countries to change clubs.

Somewhat different, Nourry (2009) examined the stochastic convergence hypothesis of two air pollutants, CO_2 and SO_2 emissions using a pair-wise approach. The samples for CO_2 emissions covered 127 countries from 1950 to 2003 and SO_2 emissions, 81 countries from 1950 to 1990. Her results were contrary to the hypothesis of stochastic convergence in CO_2 emissions per capita. However, her findings supported the studies carried out by Aldy (2006) and Barassi, Cole and Elliot (2008) concerning the stochastic divergence in per capita CO_2 emissions. The same results are found for SO_2 emissions per capita that invalidate the hypothesis of stochastic convergence as a whole. Bimonte (2009) analyzed the double convergence hypothesis on nineteen (19) OECD countries applying both cross-sectional and time-series tests. He explained that if per capita income of these countries converges and if the demand for environmental quality as a by-product converges as well (the double convergence hypothesis works), then both "green" β and σ convergence would emerge. The empirical results provided significant evidence that environmental policy had converged both conditionally and stochastically in the sample countries analyzed.

III. Econometric Modeling

As mentioned earlier the Phillips and Sul (2007) 'log-*t* test' model would be applied to analyze the per capita CO_2 emissions convergence for the 126 developing countries. This approach is extremely flexible in modeling a large number of transition paths to convergence. It investigates the convergence dynamics of CO_2 emissions and determine the convergence or divergence patterns of CO_2 emissions across regions. It may clarify further whether an unconditional (absolute) or a conditional converging economy that exists for these developing nations. This technique is described more detailed in the next part.

The significant of the technique is that it captures the heterogeneous agent behavior in economic theory and to be able to empirically model the behavior for panel study in practical work. Phillips and Sul (PS), (2007) have extended their idea by firstly allowing the systematic idiosyncratic element to evolve over time and secondly developing an econometric test of convergence for the time varying idiosyncratic components. Therefore, the new model has a nonlinear time varying common factor representing a set of observable series denote by y_{it} for country *i* is shown as:

$$y_{it} = \delta_{it}\,\mu_t \tag{1}$$

Where μ_t is a single common component, and δ_{it} is a time varying idiosyncratic element which captures the deviation of country *i* from the common path defined by μ_t. All *N* economies within this framework, either in terms of the entire sample or within the cluster will converge at some point in the future, to the steady state if $\lim_{k\to\infty} \delta_{it+k} = \delta$ for all $i = 1, 2,.......N$, irrespective of whether countries are near the steady state or in transition. This is essentially so given that the paths to the steady state or states across countries can differ significantly. As δ_{it} cannot be directly estimated, they eliminated the common component μ_t through rescaling the panel average given by equation:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} \tag{2}$$

The relative measure, h_{it}, captures the transition path with respect to the panel average. In order to define a formal econometric test of convergence, as well as an empirical algorithm of defining club convergence, the following semi-parametric form for the time varying coefficients δ_{it} is assumed:

$$\delta_{it} = \delta_i + \frac{\sigma_i\,\xi_{it}}{L(t)\,t^{\alpha}} \tag{3}$$

Where $\sigma i > 0$, $t \geq 0$, and ξit are weakly dependent over *t*, but iid(0,1) over *i*. The function *L(t)* is a slow varying function such that *L*(*t*) is equal to log(*t*) for which, increasing and divergent at infinity. Under this specific form δ_{it}, the null hypothesis of convergence for all *i*, takes the form:

$$H_0 : \delta_i = \delta \text{ and } \geq 0$$

against the alternative hypothesis of non-convergence for some *i*, is expressed as:

$$H_0 : \delta_i \neq \delta \text{ or } < 0$$

They also showed that the null of convergence can be tested in the framework of the following regression:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = \hat{c} + \hat{b}\log t + \hat{u}_t \tag{4}$$

For $t = [rT], [rT] + 1,\ldots, T$, and $r > 0$. Based on their recommendation, the chosen *r* values in the interval are estimated to be 0.2 and 0.3. In the above regression $H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2$ and $\hat{b} = 2\hat{\alpha}$, where h_{it} is shown as in equation (2), and $\hat{\alpha}$ is the least squares estimator of α. Under the null hypothesis of convergence, the dependent variable diverges whether $\alpha > 0$, or $\alpha = 0$. In this case, the convergence hypothesis can be tested by a *t*-test of the inequality, $\alpha \geq 0$. The *t*-test which PS called the one-sided *t*-test is based on $t_{\hat{b}}$, the log (*t*) test, due to the presence of the log *t* regressor shown in the above equation. It is said that the log *t* test has favorable asymptotic and finite sample properties. Its statistics is the standard normal distribution asymptotically and can be constructed using a heteroskedasticity and autocorrelation consistent standard error.

An interesting issue in the analysis that PS reminded is the possible existence of multiple equilibriums. They explained when this occurs rejection of null hypothesis that all countries in the sample are under convergence does not imply the absence of different convergence clubs in the panel. Hence, they developed the model further by introducing the four steps or procedures of which one could identify countries that form club convergences resulting from numerous equilibriums. However, the club convergence and clustering procedures will not be explained here since this study will only focus on determining whether the developing countries show a convergent or divergent pattern.

IV. Sources of Data

CO_2 is name by the Intergovernmental Panel on Climate Change (1995) report to be the most significant among the heat-trapping greenhouse gases that human beings are adding to the atmosphere. Although there are other greenhouse gases which are responsible for damage to the environment, CO_2 contributes the largest proportion i.e. 63 percent of emissions. Majority of the empirical studies concentrate on CO_2 due to the ease of availability of data. Generally, the emissions stem from the burning of fossil fuels and the manufacture of cement and also during consumption of solid, liquid, and gas fuels and gas flaring. The source of CO_2 emissions data all countries come from the Carbon Dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, US. Its value is measured in metric tons per capita.

V. Empirical Findings

In discussing the empirical findings, two important criteria to note: Firstly, the annual data on per capita CO_2 emissions must be available for all countries for the chosen years (1971-2009) thus if data is not available for any years the country will be excluded from the analysis. In this study the accessible number of countries is thus 113 out of the initial 126 developing countries. The list of countries is given in Appendix 1. Secondly, the investigations and discussions carry out begins with the 113 developing countries before proceeding to each individual region. Table 1 shows the evidence of the estimated coefficient values, *b*, including the corresponding *t*-statistics based on the regression for the whole developing region as well as individual region.

Table 1: Results of log-*t* Convergence Tests

Region	$\hat{b}$	(t-stat)	Remarks
The Whole Region	0.255	(0.629)	Convergence
Africa	-1.050*	(-25.860)	Divergence
Latin America & the Caribbean	0.156	(1.294)	Convergence
Middle East & North Africa	-0.493*	(-12.414)	Divergence
Asia & the Pacific	-3.129*	(-9.482)	Divergence

Notes: Asterisk (*) denotes rejection of the null hypothesis of convergence at 5 percent level.

Table 1 shows that the point estimate of $\hat{b}$ for the whole region is significantly a positive 0.255 whilst the *t*-statistic has a value of 0.629 (greater than zero) showing strong evidence in support of the null hypothesis of convergence behaviour of per capita CO_2 emissions among these developing regions. However, the finding differs from that of Kinda (2011) who did a similar study for the period 1970 to 2004 for 63 developing countries though the study by Westerlund and Basher (2008) found convergence among 12 developing nations. Phillips and Sul (2007) further state that if the common stochastic trend component follows either a random walk with a drift or a trend stationary process, then the speed of convergence parameter is significantly below 2, so that the absolute level convergence can be rejected. Absolute or unconditional convergence, as discussed earlier, refers to the one equilibrium-level to which all economies approach. In the case of the entire developing region, though the null hypothesis is strongly accepted, the estimated coefficient *b* has a value that is significantly below 2 meaning the hypothesis of absolute level convergence is rejected.

The study on individual regions is conducted to gain much better analysis of the transition impact on the log-*t* test. The findings shown in the table show proof that though convergence in per capita carbon emissions has also occurred in the region of Latin America and Caribbean, with the point estimate of *b* and *t*-statistics equal to +0.156 and 1.294 respectively, once more the rate of convergence indicated by the *b* parameter is below 2, implying rejection of absolute convergence in the region. In other words, a conditional convergence has taken place in both the entire developing economies and the Latin America region but the equilibrium that occurs varies by the economy of the countries or regions, and each particular country or region has its own unique equilibrium. On the other hand, the three other regions, namely, Africa, Middle East and North Africa, and Asia Pacific display diverging behavior in per capita carbon emissions. The negative scores of the estimated coefficients of the log-*t* regression rejected the null hypothesis of full convergence at the 5 percent level since the *t*-statistic of the coefficients are significantly well below the critical value of -1.65 proving the divergence behavior of carbon emissions in these three regions.

According to theory, the relative transition paths of h_{it} can be calculated to examine the behaviour of the individual country's per capita CO_2 emissions with the assumption of convergence stated for the full panel of countries, the relative transition path tends to unity for all countries. Thus, the relative transition paths for all the developing countries were plotted after eliminating the business cycle components via Hodrick-Prescott's filter, as shown in Figure 1.

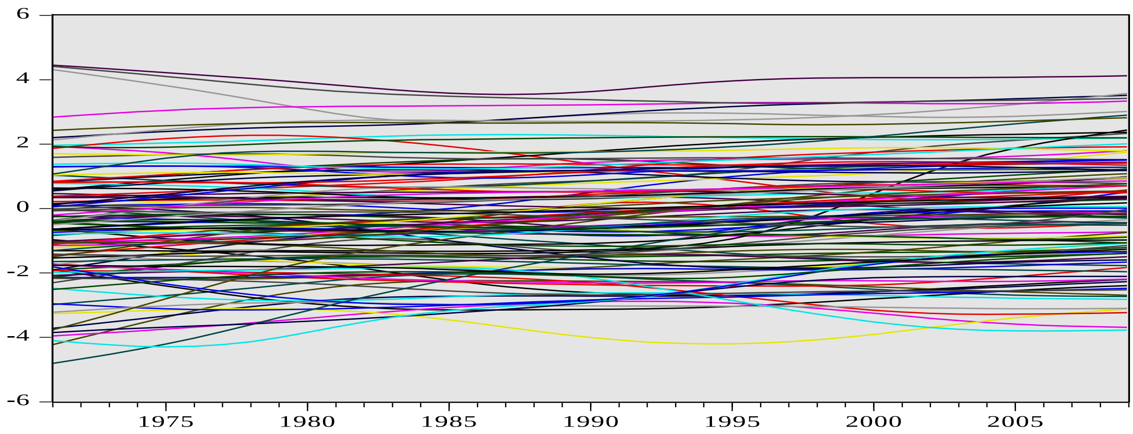

Fig. 1: Transition Paths of Developing Region Per Capita Emission

The diagram reveals reasonable evidence in support of heterogeneity of the relative transition paths of log per capita CO_2 emissions across these countries including a relatively fair view of the transition curves tending towards unity. Phillips and Sul (2007) further clarify that when divergence occur evidence of club convergence could arise because some groups of countries may converge to different equilibria meaning the relative transition paths of the groups of countries of each club converge to different constants.

VI. Conclusion

This study adds to the existing literature by investigating convergence in per capita CO_2 emissions among 126 developing countries for the period 1971 to 2009 based on the methodology proposed by Phillips and Sul (2007). The existence of convergence among the whole developing regions is crucial for policymakers to come up with proper suggestions and appropriate measures on policies to control CO_2 emissions. Stegman (2005) had expressed her concern that a policy proposal which is based on convergence in emissions per capita would cause more controversy if the emissions per capita do not show a tendency to move towards convergence.

The outcomes of the analysis found that the developing regions displayed significant convergence of per capita CO_2 emissions whereas when examined regionally three of the regions, namely, Africa, Middle East and North Africa, and Asia-Pacific, illustrated a divergence of per capita CO_2 emissions. The only region that portrays a convergence pattern is Latin America and the Caribbean (LAC). The speed of convergence rate is similar for both LAC and the whole developing region i.e. stated a coefficient (*b)* value below 2 that implies a conditional convergence. Thus, one policy implication is that any form of international emission abatement obligations would be agreed upon by the developing nations. However, about the divergent pattern of per capita CO_2 emissions found in the three regions, it implies that individual policymaking strategies should cater, if possible, for each country's specific circumstances. Thus, in other words a strategically planned national policy on cutting per capita CO_2 emissions by local policymakers would be more applicable and appropriate.

Appendix

List of developing countries representing the four regions:

Africa: Angola, Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Rep., Chad, Comoros, Congo DR, Côte d'Ivoire, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Sao Tome & Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe.
Latin America & The Caribbean: Antigua & Barbuda, Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominica Rep, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, St. Vincent & the Grenadines, Suriname, Trinidad & Tobago, Uruguay and Venezuela RB.
Middle East & North Africa: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Jordan, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia and UAE.
Asia & Pacific: Afghanistan, Bhutan, Brunei, Cambodia, China, Fiji, India, Indonesia, Kiribati, Maldives, Nepal, Pakistan, Republic of Korea, Lao PDR, Malaysia, Mongolia, Myanmar, Papua New Guinea, Philippines, Samoa, Solomon Islands, Singapore, Sri Lanka, Thailand, Tonga, Vanuatu and Vietnam.

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