EXAMINING THE EXISTENCE OF CO_2 EMISSION PER CAPITA CONVERGENCE IN EAST ASIA

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Abstract

The 'flying geese' model of industrial upgrading depicts the income convergence or economic development convergence in East Asia. However, how does this convergence of economic development effect the environment? The surge in the consumption of fossil fuel is causing a large increase in emission of CO2. Global warming affected by CO2 emission poses as a serious threat to East Asian countries with large coastal areas exposed to the rise in sea level. This paper examines CO2 emission per capita to investigate the existence of environmental convergence in East Asian countries and predicts future distribution using deviations, interquartile range, kernel densities distribution, time series approach, β convergence analysis and the Markov chain approach. As a result, no meaningful evidence of convergence was found in the historical evaluation and a non-compressed ergodic distribution was found in the future prediction for CO2 emission.

Keywords: environmental convergence, East Asia, CO2
JEL classification: Q53, Q56, R10

1. Introduction

Question of convergence in pollutant emissions between countries have recently been investigated following the studies performed on economic convergence which suggests that poorer regions should "catch up" to relatively richer regions over time. As there have been numerous empirical analyses comparing different regions which support the economic convergence hypothesis (e.g. Barro, 1991; Carlino and Mills, 1993; Cole and Neumayer, 2003; Evans and Karras, 1996)[1], studies have been performed to see whether there would be a convergence during a period of time if countries with low emission per capita increased their emission per capita and in the opposite, high emission countries decreased their emissions per capita (List, 1999; Strazicich and List, 2003; Nguyen Van, 2005). This environmental convergence hypothesis is closely related to the economic convergence hypothesis and the existence of an Environmental Kuznets Curves (EKC) or an inverted U-shape curve for the relationship between pollutant emission and income (Strazicich and List, 2003; Nguyen Van, 2005). As we follow the theoretical and empirical arguments on the EKC where environmental quality first declines and then increases as per capita income rises (e.g. Lopez, 1994; Andreoni and Levinson, 2001; Stokey, 1998; Grossman and Kruger, 1995; Cole *et al*., 1997; Holtz-Eakin and Selden, 1995), it has been argued that environmental quality will converge across regions if per capita income converges. In other words, pollutant emissions increase with income in lower income countries but decrease with income in higher income countries and all countries will have the same income level following the economic convergence hypothesis. Therefore, if the EKC and economic convergence hypotheses are valid, we will expect an environmental convergence (Nguyen Van, 2005).

If we focus on the East Asian economy, there are numerous studies on its rapid economic growth and empirical studies on the income convergence or economic development

[1] There are also studies which do not find income convergence. Some examples are the study by Dobson and Ranlogans (2002) on Latin American countries over the period of 1970 to 1998 and the study by Su (2003) on 15 OECD countries.

convergence in East Asia (e.g. Zhang, 2001; Zhang, 2003; Yap, 2005; Hsiao and Hsiao, 2004; Jayanthakumaran and Lee, 2013). The 'flying geese' model of industrial upgrading depicts this "catching up" found amongst the East Asian economies (Akamatsu 1935, 1962; Kojima, 2000; Kojima and Ozawa, 1984, 1985). The logic of the 'flying geese' model of relocating production process to cheaper areas abroad as domestic costs rise (Pangestu and Gooptu, 2003) also supports the notion of countries with low emission per capita increasing their emission per capita with the increase in production and in the opposite, high emission countries decreasing their emissions per capita. However, what does it mean when poorer regions specialize in the production of pollution-intensive goods to experience large increases in per capita income in order to catch up to richer regions specializing in the production of clean goods and subsequently have a lower growth rate in per capita income? Does this mean that the regions are converging in monetary wealth but diverging in environmental quality (List, 1999)?

This is a serious question to East Asian economies which face environmental problems caused by increasing industrialization (Asian Development Bank, 2001, 2005). The surge in the consumption of fossil fuel is causing a large increase in emission of CO_2. Global warming effected by CO_2 emission impacts the coastal regions with the rise in sea level. With many of the East Asian countries exposed to large coastal areas, this poses as a serious threat. For example, the potential land loss resulting from sea-level rise and the number of people exposed for Indonesia is 60 cm and 1.1 million people. For Vietnam, there is the potential of 50 cm rise in sea-level, effecting 23 percent of the population (IPCC, 2001).

In this paper, we examine CO_2 emission per capita between 1960 and 2000 to examine the existence of environmental convergence in East Asian countries. There are not many empirical studies on environmental convergence and to the best of my knowledge, there is no environmental convergence study on East Asian countries. So this paper will be the first to attempt to examine whether the previous studies on income convergence among East Asian countries can be supported by a convergence of environmental quality. The other characteristic of this paper is that it applies an extensive range of methods to examine the convergence of environmental quality amongst East Asian countries. These methods are deviations, interquartile range, kernel densities distribution, time series approach and β convergence analysis. It also predicts future distribution using the Markov chain approach.

The remainder of this paper proceeds as follows: Section 2 provides a brief review of the environmental convergence literature, data description, and explains the empirical methods that were used. Section 3 presents the results from the empirical studies and Section 4 provides concluding comments and discusses policy implications.

2. Previous research, data and empirical methods

2.1. Previous research

There are several studies that have undertaken this question on convergence/divergence of environmental quality. Developing the Solow growth model (Solow, 1956) which applies technological progress in abatement and pollution, Brock and Taylor (2004, 2010) examine CO_2 convergence among OECD countries. They find convergence concerning CO_2, using a cross-sectional analysis. Alvarez *et al.* (2005) develop a neoclassical growth model augmented to incorporate the dynamics of a stock of pollutant and examine convergence concerning some air pollutants per capita (SO_2, NO_2, CO_2, CO and MVOC) among European countries between 1990 and 2000. The results showed environmental convergence for most of the air pollutants. Strazicich and List (2003) study the case of CO_2 among industrial countries, using both the cross-sectional and the time series approach and find that CO_2 emissions have converged. These studies all focus on cross–country environmental convergence. However, there are also some studies which focus on a specific country- i.e. US. Using both cross-sectional convergence analysis and stochastic convergence analysis, List (1999) examines SO_2 and NOx data for regions in the US between 1929 and 1994. He finds convergence of these emissions. Bulte *et al.* (2007) examine the role institutional context has on environmental convergence, focusing on SO_2 and NOx cases among US regions. Using the stochastic convergence analysis and the time-series tests for β convergence, they find that regulations, especially federal ones, have impact on environmental convergence. Production CO_2 emission per capita and consumption CO_2 emission per capita for the US states are studied by Aldy (2007) who finds production CO_2 emission per capita to diverge, but consumption CO_2 emission per capita to converge. This was due to the effect of increasing interstates' electricity trade over time. There are also some previous studies which observe the world as well as developed countries. Stegman (2005) analyses CO_2 emission per capita convergence for the world and OECD countries. The results of considering intra-distribution dynamics show that CO_2 emission per capita does not converge over the period between 1950 and 1999. Nguyen Van (2005) also takes intra-distribution dynamics into account as well as the traditional average behaviour approach, and examines CO_2 emission per capita for both the world and industrial countries. The results showed divergence for the world and convergence for industrial countries. Empirical research by Aldy (2006) uses various methods including intra-distribution dynamics and the time series approach to examine if CO_2 emission per capita converges over time for both the world and OECD countries. Further examination is conducted using the Markov transition approach to predict future distribution. This study predicts environmental convergence among OECD countries while environmental divergence among the world.

2.2. Data description

To examine whether environmental quality have converged across the East Asian countries, this paper uses CO_2 as an indicator of environmental quality. The data for CO_2 is from the World Development Indicators (World Bank, 2005). The period from 1960 to 2000 is used. These emissions are divided by population which is sourced from the World Development Indicators (World Bank, 2005). East Asian countries sampled here for CO2 emission per capita are: Japan, Korea, China, Singapore, Thailand, Philippines, Cambodia, Hong Kong, Indonesia, Lao PDR, and Myanmar (11 countries).

2.3. Empirical methods

In order to assess the cross-sectional convergence of CO_2 emission per capita over time for East Asia, this paper conducts five types of analysis. First of all, it estimates a variety of deviations to measure the spread of CO_2 emission per capita.

The standard deviation (*SD*) of the data is represented as:

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N-1}}, \quad (1)$$

where *i* denotes country, and *N* is the number of countries. X_i is the natural logarithm of CO_2 emission per capita of country *i*. $\bar{X}$ represents the average natural logarithm of CO_2 emission per capita of East Asia observed. Standard deviation is an appropriate method with data that exhibits normal distribution, since it represents the spread of the data around the centre and in the tails of the distribution. However, if the data does not exhibit normal distribution, the average absolute deviation or the median absolute deviation may be more used (Stegman, 2005). We define the average absolute deviation (*AD*) as

$$AD = \frac{\sum_{i=1}^{N}(|X_i - \bar{X}|)}{N}, \quad (2)$$

where $|X|$ is the absolute value of *X*.

The median absolute deviation is less affected by outliers (i.e. extreme observations) in tails of the distribution of the data, compared to the *AD*.

The median absolute deviation (*MD*) is defined as

$$MD = median(| X_i - \overset{*}{X} |), (3)$$

where $\overset{*}{X}$ represents the median of the data.

As the above measures consider the spread in the tails of distribution of the data set, we will next calculate the inter-quartile range (IQR) in order to measure the spread in the centre of the distribution of the data set. *IQR 75-25* is the value of the 75th percentile minus the value of 25th percentile. Since the IQR is sensitive to the percentile points, we also estimate *IQR80-20* which the value of the 80th percentile minus the value of 20th percentile.

To illustrate the CO_2 emission trend, we next present the estimated kernel densities of CO_2 emission per capita. Intra-distribution dynamics which may not be captured by the deviations and IQRs described above can be observed with this method. A country's per capita emissions are expressed as natural logarithm of its emissions per capita relative to the observed East Asian average (*z*). We have used the Espanechikov kernel and Silverman's (1986) bandwidth choice rule to estimate the densities. This produces a kernel density estimator function of

$$d(z) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{z_i - z}{h}\right), (4)$$

where $K = \frac{3(1-0.2z^2)}{4\sqrt{5}}$ if $|z| < \sqrt{5}$, and 0 otherwise,

$$h = \frac{0.9\left(\min\left(s, \frac{I}{1.349}\right)\right)}{\sqrt{5}}, \text{ and}$$

N reflects the number of countries, *I* is the *IQR 75-25* for the sample used, and *s* is standard deviation of the observed sample. The Espanechikov kernel is applied as it is the most efficient kernel function to minimize the mean integrated square error (Aldy, 2007) and the Silverman bandwidth choice rule is often employed in density estimation.

Next we will examine the convergence of CO_2 emission per capita using the parametric approach. We test for whether a unit root characterizes the time series of CO_2 emission per capita to assess stochastic convergence. If stochastic convergence is found for CO_2 emission per capita, then the shocks to CO_2 emission per capita are temporary and the data are stationary over time, suggesting that CO_2 emission per capita are converging. However, if a unit root can be confirmed in the time series of CO_2 emission per capita, then the shocks are permanent and CO_2 emission per capita are not stationary over time and not converging. As many studies have used unit root tests to evaluate income convergence (e.g. Carlino and Mills, 1993; Li and Papell, 1999; Loewy and Papell, 1996; Oxley and Greasley, 1995; Tsionas, 2000), unit root tests have been conducted for emissions convergence. List (1999) performed unit root tests and examined the US regions' convergence of NOx per capita and SO_2 per capita. Aldy (2006, 2007) examine CO_2 emission per capita for both the US regions and the world/OECD and Strazicich and List (2003) examine the industrial countries for CO_2 emission per capita with this test.

We have used the same panel-based unit root test as the one developed by Im *et al*. (2003) to examine the existence of stochastic convergence amongst countries' CO_2 emission per capita. This requires country-specific augmented Dickey-Fuller tests which is constructed by estimating the following specification on a county-by-country basis:

$$\Delta x_{it} = \varpi_i + \theta_i t + \pi_i x_{it-1} + \sum_{k=1}^{l} \eta_{ik} \Delta x_{it-k} + \nu_{it}, (5)$$

where x_{it} represents the natural logarithm of CO_2 emission per capita relative to the East Asian average observed for each country for each year. ϖ_i represents the constant term specific to each country, and $\theta_i t$ indicates a linear time trend. π_i depicts the parameter to test the null of a unit root. l defines the maximum number of lagged terms Δx_{it-k}, and η_{ik} represents a parameter estimated for each first-differenced lagged term. v_{it} represents the contemporaneous error term and is assumed to be independent and identically distributed (*i.i.d.*) with zero mean and finite variance. Perron's method (1989) was used for the lag selection[2].

After estimating equation (5) for each country, by averaging the country-specific augmented Dickey-Fuller statistic, the Im *et al*. (2003) test statistic is created:

$$\bar{t}_{NT} = \frac{1}{N}\sum_{i=1}^{N} t_{\pi}^{i} \text{ . (6)}$$

Im *et al*. (2003) shows that this test is more powerful in rejecting the null hypothesis that unit roots are confirmed for all the time series observed, compared to the individual augmented Dickey-Fuller tests. In their study, they also compute sample critical values via stochastic simulation which we use to evaluate the panel-based test statistic for relative CO_2 emissions per capita. This method by Im *et. al* (2003) is a useful method to confirm whether the panel data is stationary by performing the test of null hypothesis of unit root. However, unless there is strong evidence to the contrary, it is well known that the null hypothesis is accepted. In order to reconfirm whether the panel data on emissions per capita is stationary, we will undertake the Hadri (2000) test to complement the limitations of Im *et al*. (2003). In other words, we will perform the test of null hypothesis of stationarity with the error term being *i.i.d.*. We, furthermore, extend heterogeneous errors across country and apply serially correlated disturbance terms according to the work by Hadri (2000).

Following the work by Hadri (2000), we consider the following two models to examine whether CO_2 emission per capita is stationary around a level and whether it has trend stationary.

$$y_{it} = r_{it} + \varepsilon_{it} \text{ , (7)}$$

$$y_{it} = r_{it} + \phi_i t + \varepsilon_{it} \text{ . (8)}$$

Here r_{it} is a random walk:

$$r_{it} = r_{it-1} + u_{it} \text{ . (9)}$$

i is country and *t* denotes year. *y* is CO_2 emission per capita relative to the East Asian average observed here. ε_{it} and u_{it} are mutually *i.i.d.* across *i* and over *t* with $E[\varepsilon_{it}]=0$, $E[\varepsilon_{it}^2]=\sigma_\varepsilon^2$, $E[u_{it}]=0$ and $E[u_{it}^2]=\sigma_u^2$. Equation (7) represents the model to perform the test of the null hypothesis of stationarity around a level. By using back substitution, we obtain the following equation:

$$y_{it} = r_{i0} + \sum_{t=1}^{t} u_{it} + \varepsilon_{it} \text{ . (10)}$$

[2] See List and Strazichi (2003).

The initial values r_{i0} are treated as fixed unknowns and play the role of heterogeneous intercepts. On the other hand, Equation (8) represents the model to perform the test of the null hypothesis of trend stationarity. By also using back substitution, we derive the following equation:

$$y_{it} = r_{i0} + \phi_i t + \sum_{t=1}^{t} u_{it} + \varepsilon_{it} \,. \quad (11)$$

In order to perform the test of stationarity around a level, Hadri (2000) first regresses dependent variable *y* on an intercept for equation (7) and on an intercept plus a time trend for equation (8), and derives the residuals. By using the residuals, Hadri (2000) calculates the Lagrange multiplier (LM) statistic under the assumption that ε_{it} and u_{it} are mutually independent normals and *i.i.d* across *i* and over *t*. As used by Hadri (2000), the residual-based LM statistic is:

$$LM_{\mu} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\frac{1}{T^2}\sum_{t=1}^{T} S_{it}^2}{\hat{\sigma}_{\varepsilon}^2}\right) , \quad (12)$$

Where

$$S_{it} = \sum_{j=1}^{t} \hat{\varepsilon}_{ij}$$

$$\hat{\sigma}_{\varepsilon}^2 = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{\varepsilon}_{ij}^2 \,.$$

To confirm whether all time series are stationary, he uses the fact that the limiting distribution of the test statistic, which is derived by subtracting the means from the LM statistic and dividing it by the standard deviation, weakly converges to normal distribution as follows:

$$Z_{\mu} = \frac{\sqrt{N}}{\zeta_u}(LM_u - \xi_u) \Rightarrow N(0,1) \,. \quad (13)$$

Next in order to take into account the heterogeneous errors across *i*, Hadri (2000) computes σ_{ε} for each *i*, and substitutes it for the above LM statistic and then derives the LM statistic under heterogeneous errors across *i* as follows:

$$LM_{\mu}^{h} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\frac{1}{T^2}\sum_{t=1}^{T} S_{it}^2}{\hat{\sigma}_{\varepsilon,i}^2}\right) \,. \quad (14)$$

Furthermore, when taking into consideration serially correlated disturbance terms[3], he

[3] To consider quiet general forms of temporal dependence over *t*, Hadri (2000) assumes either that ε_{it} satisfy the strong mixing regularity conditions of Phillips and Perron (1988) or the linear process conditions of Phillips and Solo (1992).

replaces σ_ε by the long-run variance σ and computes the LM statistic:

$$LM_{\mu}^{s} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\frac{1}{T^2}\sum_{t=1}^{T}S_{it}^2}{\hat{\sigma}^2}\right) \quad , (15)$$

Where

$$\sigma^2 = \frac{1}{N}\sum \lim_{T\to\infty} T^{-1}(S_{iT}^2).$$

Concerning LM statistic and Z statistic to perform the test of the null hypothesis of trend stationarity, the procedure is similar to the above procedure to derive LM statistic and Z statistic to perform the test of the null hypothesis of being stationary around a level except for the usage of residuals which is computed by regressing dependent variable on an intercept and a time trend for equation (8).[4] In this paper, we employ the above residual-based LM statistic to perform the test of the null hypothesis of stationarity for panel data to examine whether relative CO_2 emission per capita converges in East Asian countries.

Next we will examine the convergence of CO_2 per capita using the parametric approach which is familiar in growth empirical literature. We use the technique called *β*-convergence that was developed by Baumol (1986).

$$Cg_i = \alpha + \beta C_{0i} + e_i \, , (16)$$

where Cg_i denotes the average annual growth rate of the natural logarithm of CO_2 emission per capita for each country *i* over the sample period between 1960-2000. α is a constant term, and β is the parameter to test the null hypothesis of divergence. C_{0i} denotes the natural logarithm of the initial value of CO_2 emission per capita in country *i*. e_i is the contemporaneous error term which is assumed *i.i.d.* with zero mean and finite variance. $\beta < 0$ will represent a convergence in CO_2 emission per capita. $\beta = -(1-\exp^{-\lambda\tau})$ where τ denotes the length of the study period and λ represents the convergence speed[5].

The above methods were used to examine the historical convergence of CO_2 emission per capita. Next, we examine future CO_2 emission distribution. For the purpose of estimating future distribution, we perform a Markov chain transition matrix analysis, which is based on a nonparametric method employed in economic growth studies to evaluate income distribution. The transition matrix framework has been used by Quah (1993) to evaluate the distribution of per capita income. Following this study by Quah (1993), Aldy (2006, 2007) examines the CO_2 emission per capita for the US regions and the world/OECD. This paper will also use the transition framework to map this year's distribution (W_t) of per capita emissions relative to the East Asian average sampled here into next year's distribution (W_{t+1}):

$$W_{t+1} = M * W_t \, . (17)$$

[4] More precisely speaking, the LM statistic and Z statistic to perform the test of the null hypothesis of stationarity around a level is different from the test of the null hypothesis of trend stationarity in the function of the Brownian motion and the characteristics function which is used for computation of mean and variance of the LM statistic.

[5] λ can be estimated and its variance calculated by using the delta method once the estimate of β is available.

The mapping operator M can be used to work with any process, but similar to Aldy (2006, 2007), Quah (1993) and Kremer *et al*. (2001), this paper assumes a first-order Markov process with time invariant transition probabilities. Repeating this expression T times produces

$$W_{t+T} = M^{T} * W_{t} . (18)$$

The larger T becomes and if $W_{t+T} = W_{t+T-1}$, this can express the long-run steady state (ergodic) distribution of relative per capita emissions.

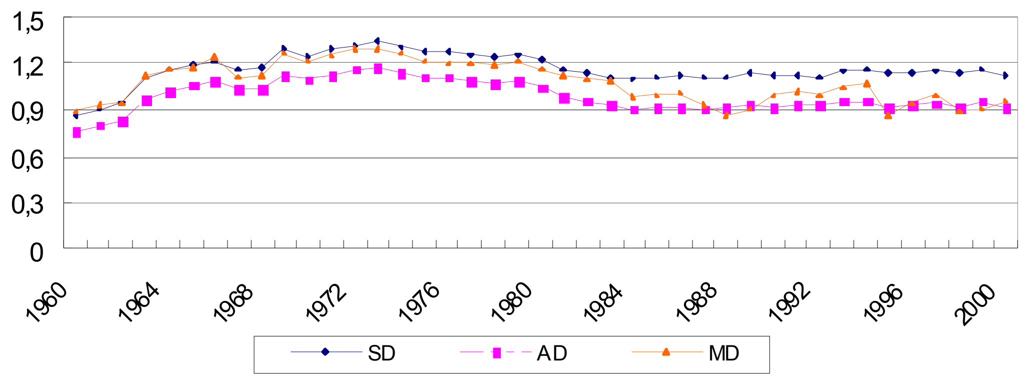
We first allocate the East Asian countries according to the five categories of relative per capita emissions relative to the East Asian countries' average as conducted by Aldy (2007) in his study on environmental convergence and Quah (1993) and Kremer *et al*. (2001) in their income convergence studies. The five categories are: relative per capita emission less than 50 percent of the East Asian average, between 50 percent and 75 percent of the East Asian average, between 75 percent and 100 percent of the East Asian average, between 100 percent and 200 percent of the East Asian average, and greater than 200 percent of the East Asian average. In order to produce the transition matrix, we next compute the one year transitions between categories. The mapping operator is then applied to the distribution in the last year of the data set to forecast the future distribution for the data set. The advantage of this analysis is that the changes to the data over time can be shown with limited constraint, since the analysis does not require much structure to the data. We only applied the five categories and the first-order Markov assumption. However, this analysis has several limitations. This approach can illustrate future distribution, but does not explain the reason why the emission in the 1960s may be different from those in the 1970s, 1980s or 1990s. Following Aldy (2006, 2007), we address this issue by comparing the ergodic distribution derived from transition probabilities based on various periods. The other limitations is that since this approach uses data from past distributions to forecast future distributions, changes that have occurred in the past such as in policies, institutions or technologies are not well expressed in this analysis.

3. Results

3.1. Historical results

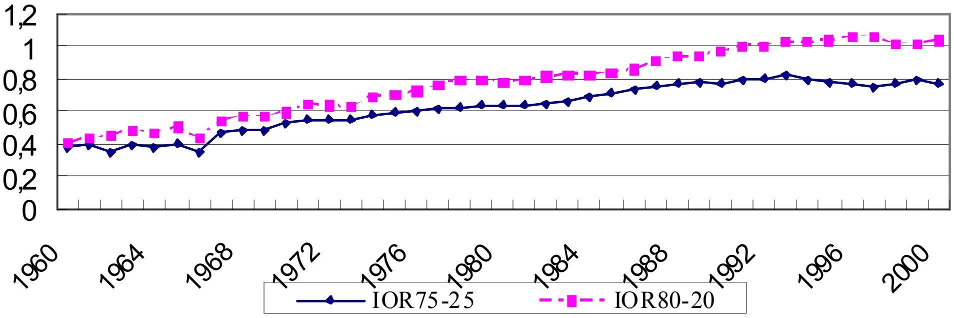
First of all, we analyse the results on historical evaluation of CO_2 emission per capita. Figure 1 illustrates estimates of each of the measures for deviations over the period between 1960 and 2000 for CO_2 emission per capita. The results of the CO_2 emission per capita in Figure 1 shows an increase till the early 1970s followed by a decrease to the early 1980s and then is stable. However, the end of the sample period is also higher than the start of the sample period which is evidence of divergence for CO_2 emission per capita.

Figure1. Deviations of CO_2 per capita



According to the IQR which focuses on the centre of distribution of the data, Figure 2 displays an increase of CO2 emission per capita and thus indicates a consistent divergence. The IQR80-20 which displays a stronger increase trend indicates that the further the observation is from the centre, there is a stronger sign of divergence. In other words, the difference in CO2 emission per capita between countries further from the centre is increasing.

Figure 2. IQRs of CO_2 per capita



The above results on deviations and the IQR analysis show that CO2 emission per capita has some periods of convergence but overall support evidence of divergence. As described in Section 2, these measures do not characterize the cross-sectional distribution. They are shown in Figure 3 which illustrates the comparison between the kernel density distributions of relative CO2 emission per capita for the start of the sampled period (1960) with the end of the sampled period (2000). The results find that the distribution of relative CO2 emission per capita in 1960 is slightly more compressed than that in 2000. This means that relative CO2 emission per capita does not converge. As illustrated in Figure 4, for relative CO2 emission per capita, the kernel density distribution for 1960 to 1964 were thicker near the average and thinner in the tails when compared to the distribution from 1996 to 2000. This suggests a divergence of relative CO2 emission per capita and supports the results of the deviations and IQRs. Furthermore, in Figure 5 when the kernel density distribution for the period of 1960 to 1969 is compared with the period of 1991 to 2000, the same results are achieved as the earlier period showing a more compact distribution indicating a divergence in relative CO2 emission per capita.

Figure 3. Comparison of kernel density distribution of first year with last year

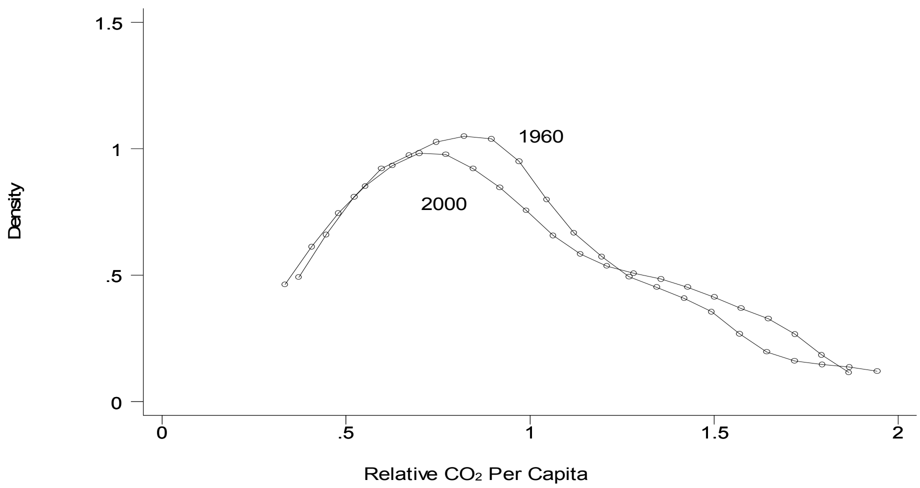


Figure 4. Comparison of kernel density distribution of first 5 years with last 5 years

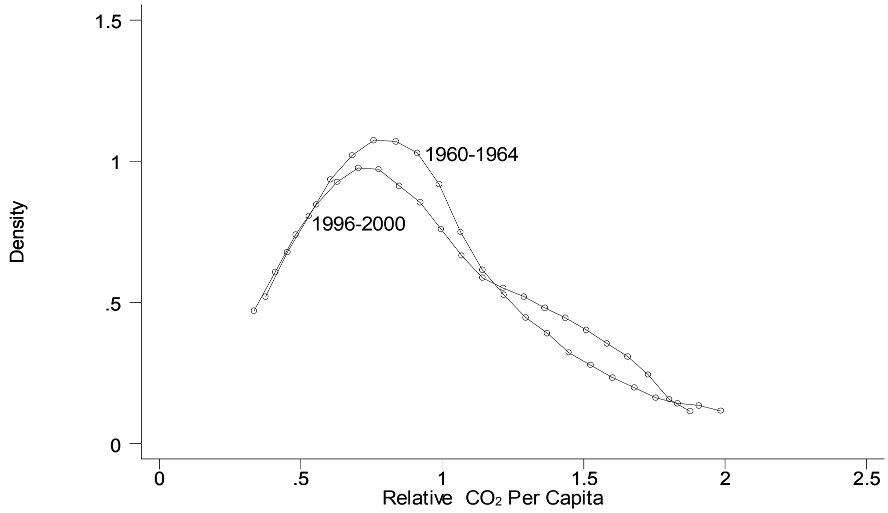
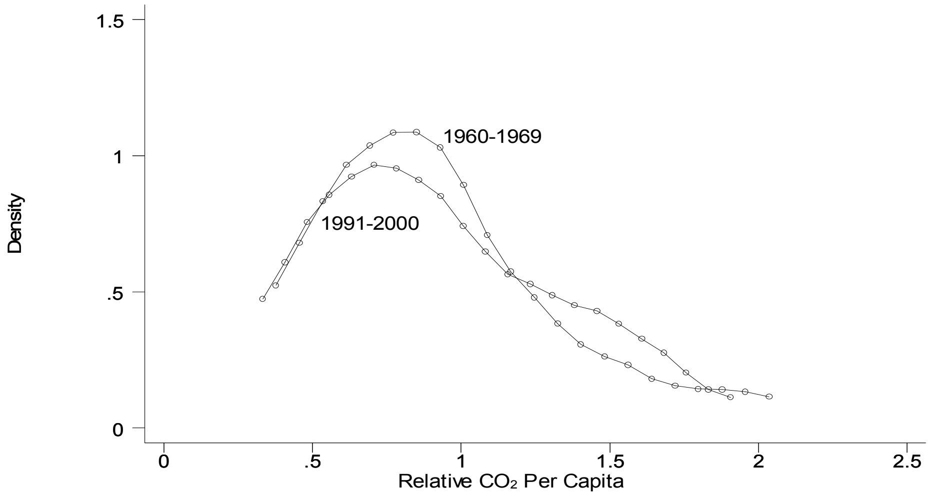


Figure 5. Comparison of kernel density distribution of first 10 years with last 10 years



The methods used above are related to nonparametric approaches. Next we will examine the convergence of CO_2 emission per capita through parametric approaches. First we will investigate the convergence of relative CO_2 emission per capita through time series analysis for the East Asian countries. According to Table 1, the Im *et al*. (2003) test statistic for relative CO_2 emission per capita is -2.14, which cannot justify rejecting the null hypothesis that the time series of the East Asian countries are characterized by a unit root. Shocks to relative CO_2 emission per capita is found to be persistent, and the East Asian countries are not converging in a stochastic sense. Table 2 shows Hadri (2000)'s test which performs the null hypothesis of stationarity with not only the error term being *i.i.d.* but also extending heterogeneous errors across country and applying serially correlated disturbance terms. The results indicate that under the error term being *i.i.d.* $Z\mu$ statistic for relative CO_2 emission per capita is 72.083, which can reject the null hypothesis that all time series in the panel are stationary process around a level. The results also shows that under the error term being *i.i.d.* $Z\tau$ statistic for relative CO_2 emission per capita is 45.498, which can justify rejecting the null hypothesis that all time series in the panel are trend stationary processes. These results show that when considering heteroskedastic distribution across units for relative CO_2 emission per capita we can also reject the null hypothesis which considers that all time series in the panel are stationary processes around both a level and a trend. When considering serial dependence in errors, Table 2 shows that we can again reject the null hypothesis for relative CO_2 emission per capita. These results support the results from the Im *et al*. (2003)'s test, the deviations, IQRs and the kernel distribution.

Table 1. Im et al. (2003) Panel-based Unit Root Tests

IPS t-statistic	10%	5%	1%
-2.14	-2.44	-2.52	-2.65

i) Test statistic constructed from CO2 of 11 countries, 41-year time series augmented Dickey-Fuller tests (with trend).

ii) The above critical value use N=15 and T=50 as in Im *et al*. (2003).

iii) The lag selection was chosen on a country by country basis using the Perron method (1989).

Table 2. Hadri (2000) Panel Unit Root Test

	$Z\mu$	P-value	$Z\tau$	P-value
Homo	72.083	0	45.498	0
Hetero	54.691	0	26.363	0
SerDep	10.093	0	6.816	0

i) H0: all time series in the panel are stationary processes (11 time series for CO2)

ii) Homo: homoskedastic disturbances across units

iii) Hetero: heteroskedastic disturbances across units

iv) SerDep: controlling for serial dependence in errors (lag truncation = 7)

The above results are also confirmed by the β convergence analysis. As illustrated in Figure 6, the plots do not show any consistent relationship between the initial level of CO_2 emission per capita and the average growth rate of CO_2 emission per capita. If we examine this further in Table 3, the results of the cross-sectional econometric analysis show significant heteroskedascity performing the Breusch-Pagan / Cook-Weisberg test. Hence, we use the OLS with robust standard error which is based on the Huber/White/sandwich estimator of variance. As a result, we find no significant evidence of convergence[6]. Through these studies, we were able to examine the representative behaviour and intra-distribution dynamics of CO_2 emissions per capita which resulted in finding environmental divergence in the East Asian countries.

[6] By using the bootstrap and the jackknife method, we conduct the estimations of standard errors. The results regarding statistical significance of initial value of CO2 per capita are the same as those from robust standard error which is based on Huber/White/sandwich estimator of variance.

Figure 6. The relationship between initial level of CO2 per capita and the average growth rate of CO2 per capita

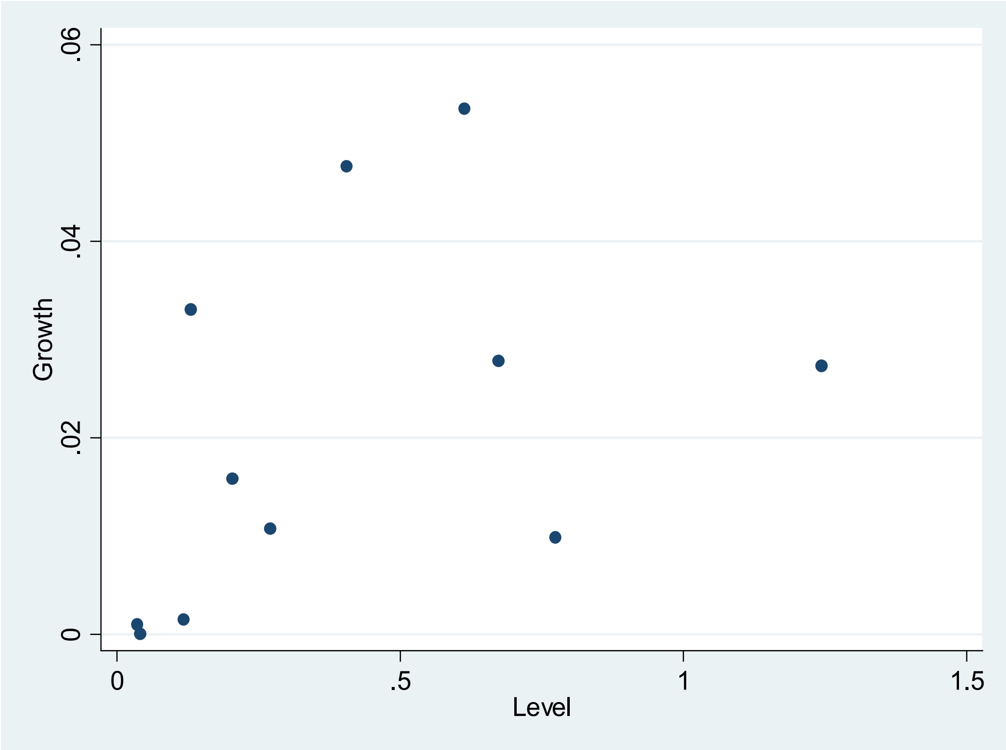


Table 3. β Convergence Analysis

	Coefficient	Robust Standard Error	P>t
β	0.205	0.119	0.119
α	0.123	0.068	0.103
λ	-0.005	0.003	0.116
Breusch-Pagan / Cook-Weisberg Test	0.06		
R-squared	0.17		
No. of Obs.	11		

Robust standard error is based on the Huber/White/sandwich estimator of variance.

Next, we observe relative CO_2 emission per capita for each country over time as illustrated in Figure 7. In the 1960s, Japan's relative CO_2 emission per capita was much higher than the average of East Asia. The less developed countries such as Cambodia and Lao PDR had a low relative CO_2 emission per capita. In the latter 1960s, Singapore had a sudden increase in relative CO_2 emission per capita and replaced Japan as the highest relative CO_2 emission per capita followed by Japan, Hong Kong and Korea. In the 1970s, countries with low relative CO_2 emission per capita continued to be the less developed countries. The results for the 1980s and the 1990s continued on a similar path with Singapore having the highest relative CO_2 emission per capita followed by Japan, Korea and Hong Kong and the less developed countries showing low relative CO_2 emission per capita. These observations of first Japan and then the newly industrialised countries having a higher than average relative CO_2 emission per capita and the less developed countries having low relative CO_2 emission per capita can be considered to have affected the relative CO_2 emission per capita divergence in East Asia.

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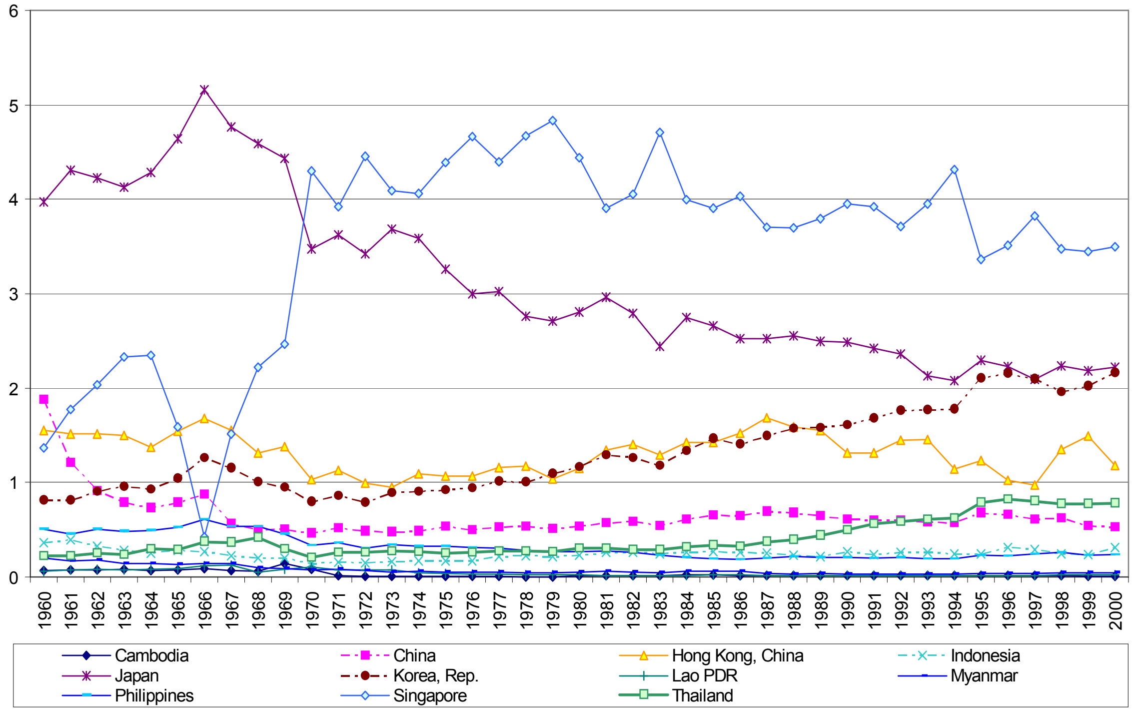
Figure 7. Relative CO2 per capita trend in East Asia



3.2. Forecasting future emission distribution

This paper will next review the results of future distribution for CO_2 emission per capita. Table 4 presents the transition matrix over 1960-2000 and the estimated ergodic distribution for relative CO_2 emission per capita. Like Aldy (2006, 2007)'s findings for the case of relative CO_2 emission per capita, the high probabilities along the diagonal suggests a high degree of persistence in countries' relative CO_2 emission per capita. The long-run steady state (ergodic) distribution of relative CO_2 emission per capita shows that around 70 percent of East Asian countries would be expected to be in the lowest or highest category of relative CO_2 emission per capita and only 21 percent of East Asian countries would have CO_2 emission per capita in two categories around the East Asia countries' average (i.e. between 0.75 and 2 of East Asian countries' average). This suggests that the distribution is not compressed around the East Asian countries' average.

Table 4. Estimates of Transition Matrix and Ergodic Distribution: Relative CO2 Per Capita – 1 Year Transitions -

			Upper Endpoint		
Upper Endpoint	0.5	0.75	1	2	∞
0.5	0.961	0.034	0.000	0.004	0.000
0.75	0.184	0.763	0.053	0.000	0.000
1	0.000	0.080	0.760	0.160	0.000
2	0.015	0.000	0.061	0.864	0.061
∞	0.000	0.000	0.000	0.025	0.975
Ergodic	0.52	0.09	0.06	0.15	0.18

The estimated ergodic distribution is likely to be effected by the sample periods to construct the transition matrix. The ergodic distribution for transition matrices for the periods between 1960 to 2000, 1970 to 2000, 1980 to 2000 and 1990 to 2000 for the East Asian sample is provided in Table 5. It also shows that the estimated ergodic distribution for transition matrices for these sample periods have a similar trend and suggests that the ergodic distributions of relative CO_2 emission per capita are not compressed around the sampled East Asian average. Furthermore, relative CO_2 emission per capita exhibits thinner bottom of the estimated ergodic distribution over shorter periods and thicker top of the estimated ergodic distribution over shorter periods.

Table 5. Estimates of Ergodic Distributions Based on Various Time Periods: Relative CO2 Per Capita – 1 Year Transitions –

			Upper Endpoint		
Time Period	0.5	0.75	1	2	∞
1960-2000	0.52	0.09	0.06	0.15	0.18
1970-2000	0.53	0.09	0.04	0.14	0.20
1980-2000	0.50	0.11	0.03	0.16	0.20
1990-2000	0.45	0.13	0.06	0.13	0.23

Further to the previous one year Markov transition matrix we also performed a five year Markov transition matrix based on the period from 1960 to 2000. As explained by Kremer *et al*. (2001), transitions periods longer than one year reduces the impact on the estimated transition matrix of high frequency fluctuation that happened to be close to the border between different groups at the beginning of the period and depicts more accurately the long-run dynamics than using annual data. According to Table 6, the relative CO_2 emission per capita results of the five year Markov transition matrix were similar to the one year Markov transition matrix and the lowest and highest category (per capita emission less than 0.5 and per capita emission more than 2 of the East Asian average) displayed high probabilities of remaining in the same category and the category around the average showed a low probability of remaining in the same category. The results also show that there was a slight increase in transition probabilities off the three diagonals that were not zero, implying that countries experiencing more than a doubling or less than halving of relative CO_2 emission per capita increases slightly over a five year period compared to a one year. It is reasonable to find this, since the allocated time for CO_2 emission per capita to change is longer in a five year period. The estimated ergodic distribution of the five year transitions were consistent to the results of the distribution of the one year transitions and displayed a non compressed distribution around the East Asian average.

Table 6. Estimates of Transition Matrix and Ergodic Distribution: Relative CO2 Per Capita - 5 Year Transitions -

			Upper Endpoint		
Upper Endpoint	0.5	0.75	1	2	∞
0.5	0.939	0.052	0.005	0.000	0.005
0.75	0.206	0.676	0.118	0.000	0.000
1	0.100	0.100	0.250	0.550	0.000
2	0.016	0.000	0.145	0.742	0.097
∞	0.000	0.000	0.000	0.015	0.985
Ergodic	0.53	0.09	0.05	0.14	0.19

Since the transition period can affect the results, in order to predict future distribution, we have based the estimated ergodic distribution for the five year transition matrices on the following periods to compare with the ergodic distribution from 1960 to 2000. The periods are from 1970 to 2000, from 1980 to 2000 and from 1990 to 2000. As displayed in Table 7, the results of the estimate ergodic distribution of the five year transitions for the relative CO_2 emission per capita were similar to the distribution of the one year transition. For all the periods, the lowest and highest categories had approximately 70 percent of the countries and the two categories in the centre had approximately 20 percent, displaying a non compressed distribution for relative CO_2 emission per capita for the East Asian countries and support the result of the distribution of the one year transition.

Table 7. Estimates of Ergodic Distributions Based on Various Time Periods: Relative CO2 Per Capita – 5 Year Transitions -

			Upper Endpoint		
Time Period	0.5	0.75	1	2	∞
1960-2000	0.53	0.09	0.05	0.14	0.19
1970-2000	0.52	0.10	0.03	0.15	0.20
1980-2000	0.46	0.10	0.04	0.16	0.24
1990-2000	0.45	0.09	0.11	0.09	0.26

4. Conclusions

The ‘flying geese’ model of industrial upgrading depicts the income convergence or economic development convergence in East Asia. However, how does this convergence of economic development effect the environment? This paper has looked at whether environmental convergence exists in East Asian countries focusing on CO_2 emission. The surge in the consumption of fossil fuel is causing a large increase in CO_2 emission, the main contributor to global warming, which is a serious threat to East Asian countries being exposed to the rise in sea level along the large coastal areas.

The paper conducted an examination of the existence of emission convergence for CO_2 emission per capita across 11 East Asian countries. The result of the deviations, IQRs, the time series analysis and β convergence analysis which tests the representative behaviour of CO_2 emission per capita, as well as the result of the kernel distribution function which examines the intra-distribution dynamics of the emission showed a divergence. Further observation of each country’s CO_2 emission per capita showed that this divergence could be explained by the higher than average CO_2 emission per capita of the NIES and Japan and a low CO_2 emission per capita maintained by the less developed countries causing a gap between these two groups.

Concerning future prediction of the convergence of CO_2 emission per capita, the analysis using the Markov transition matrix suggests that the CO_2 emission per capita across the East Asian countries show a non compressed distribution. With East Asian countries continuing to have a strong industrial growth and inter-regional foreign direct investment being a strong characteristic of the region, these results provide some insight to policy considerations. If we consider that the countries with higher than average emission per capita would adapt more stringent regulations, pollution intensive industries with heavy pollution abatement costs could decide to relocate to countries with less stringent regulations. In order to prevent the behaviour illustrated in the pollution haven hypothesis[7] such as this, policy makers would require careful monitoring and regulations. Furthermore, measures such as reducing fossil fuel related subsidies and introducing CO_2 emission tax such as polluters pay policy could help prevent 'free riding' of natural resources and environmental damage which causes environmental inequality amongst countries.

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[7] The pollution haven hypothesis are supported by empirical studies (e.g. Birdsall and Wheeler, 1993; Mani and Wheeler, 1998; Keller and Levinson, 2002; Cole and Elliott, 2005).

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