Convergence and Club Convergence of CO_2 Emissions at State Levels: A Nonlinear Analysis of the USA

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Abstract: This study examined the convergence of CO_2 emissions at state-level in the USA, for the period from 1976 to 2014, based on a nonlinear and novel empirical framework. In so doing, we have applied Pesaran's (2007) test of pair-wise approach to testing convergence which gives in general what are the rejection frequencies and thus provides evidence of convergence. At the aggregate level, we also applied Chi-Young et al. (2006) half-life convergence test and the KPSS test with Fourier transformation which states are converging towards a cross-section average. Finally, we also adopted club convergence approach developed by Phillips and Sul (2007) to identify if the states are converging towards a club and last but not least we applied Schnurbus et al. (2016) test to find if there is possible evidence if club merging. We make two contributions to the literature: (i) we conduct a country-specific analysis by focusing on the US; (ii) we consider both convergence and club convergence. Our overall results from the Pesaran's (2007) pair-wise approach of convergence indicates that about 35% of the time the null of a unit root is rejected when ADF test is used and about 22% of the time null is rejected when ADF-GLS is used (irrespective of AIC or SBIC criterion). These results are also supported by KPSS stationary test which shows that null is rejected about 70 to 80% times. However, when Fourier function is incorporated in the KPSS test we find that the null hypothesis of stationarity is rejected only for Florida, Massachusetts, Montana, Nevada, New Mexico, Rhode Island, Texas indicating that only these states are non-convergent. Our overall results from club convergence (after club merging) show that USA states are forming 4 clubs. Our findings provide new insight into the convergence of CO_2 emissions at the state level in the USA and thus have profound implications in terms of environmental policy setting and Per Capita Emission (PCE) allocations.

Keywords: CO_2 Emissions, Environmental Management, Convergence, Energy Policy, Club Convergence

JEL Classification: Q51, Q52, Q54, Q57, Q58, R11

1. Introduction

Over the past few decades, two issues have conspicuously stood out: (i) unprecedented growth in the global economy and (ii) increasing rate of pollution. The statistics on carbon dioxide (CO_2) emissions related to energy consumption suggest an increase of over 100% from 15.51 gigaton in 1975 to 32.1 gigaton in 2016 (IEA, 2017). Among the attendant effects of emission is the threat of global warming and climate change. The general position in the literature is that global warming is predominantly caused by the emissions of Greenhouse Gases (GHGs) due to excessive consumption and dependence on the fossil energy sources to fuel economic development (Chiu, 2017)[1].

There have been international concerted efforts to tame the rising wave of GHGs. For instance, a number of treaties and accords have signed by governments of sovereign nations, which include the Intergovernmental Panel on Climate Change (IPCC) founded in 1988, the Kyoto protocol initiated in Kyoto, Japan in 1997 and more recently, the Paris Climate Conference Agreement 2015 (COP21). Three factors have been identified to aid in the reduction of GHGs: mobilization and provision of financial resources; new technology adoption; and enhanced capacity building. The financial requirements to achieve these goals are enormous, thus serves as a discouraging factor. Other factors that can potentially impede the progress of this agreement include no legal bindings on emission targets; no specific financial supports; no change in specific policy premise; and no liability provision linked to financial compensation (Clemencon, 2016; Isa and Ganda, 2018).

Convergence in CO_2 emissions has been identified as an important tool that could help reduce GHGs. The fundamental problem of this approach related to the anticipated international policy agreement and allocation rules. For instance, countries with a relatively lower level of Per Capita

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[1] EAP (2020) reveals that a total of 6,677 Million Metric Tons of CO_2 was emitted in the US between 1990 and 2018. The five contributors are: Transportation (28%), Electricity (27%), Industry (22%), Commercial and Residential (12%) and Agriculture (10%).

Emissions (PCE), usually the developing countries, will favour egalitarian policy agreements because the allocation rule asserts that countries with higher PCE will carry a broader burden of the mitigation cost (Apergis and Payne, 2017; Rios and Gianmoena, 2018). This allocation problem becomes obvious and acute in a decentralized, developed and fiscal federalism practising countries- such as the United States- because of the concern over equitable and fair schemes of emissions allocation associated with the ongoing discussion at the Framework Convention on Climate Change. Although the fair share and contributions by each country (or state) to deal with the emissions is a debatable subject with a crucial political dimension, an important aspect to note at this juncture is that some scholars in the recent past (for instance, Aldy 2006, Barassi et al. 2008, Barassi et al. 2011 and Payne et al. 2014) have posited that PCE allocation schemes could cause limited concerns if emissions tend to converge over the passage of time. In fact, Apergis and Payne (2017) argue that the convergence of CO_2 emissions is the key conjecture to postulate many climate change models and thus policies. Achieving equilibrium in CO_2 emissions using such earlier cited approaches may resort to costly trade-offs i.e. higher adjustment costs and wealth transfers. Thus, it becomes imperative that CO_2 emissions must converge to specific target levels to meet the objective of curbing down the emissions level.

Hence, unravelling the convergence dynamics of CO_2 emissions, PCE has gained considerable interest in the recent literature. Furthermore, understanding the CO_2 emissions stochastic dynamics has also become inevitable to aid policymakers in designing the climate change proposals in the most efficient way (Panopoulou and Pantelidis, 2009). Acknowledging the importance of this issue in a recent study, Burnett (2016) argued that understanding the CO_2 emissions dynamics is of paramount importance to formulate an optimal mitigation policy. It implies that even in the case of persisting differences in regional emissions, a mitigation policy could be framed in a way that the underlying economic structure is least adversely impacted and abatement costs could also be optimized.

Digging deeper, a strand of the literature had shown that there is the need to account for the importance of club convergence. There is a need to look at the source and distribution of emission within a country to formulate new or ratify existing international agreements (Burnett, 2016). Hence, policymakers are interested in seeing the changing dynamics of the distribution of emission at the state level. The essence of this disaggregation is to determine whether the tail of the distribution of emission is widening or shrinking. It will also provide information on whether the policy has been effective or there is a need to make changes to it.

Based on the foregoing, the broad objective of this study is to examine the existence of convergence in CO_2 emissions for the United States of America. Also, we are investigating if there is convergence at club levels where the states can be grouped together in clubs. To empirically support our endeavour we are employing a very rich and novel set of empirical approaches. This is a major theoretical as well empirical contribution to the existing literature on the subject. Specifically, in this study, we are applying Pesaran's (2007) test of a pair-wise approach to testing convergence. Furthermore, the half-life convergence test suggested by Choi et al. (2004) is applied. At the aggregate level, we use the KPSS test with Fourier transformation as proposed by Becker et al. (2006). Thereafter, in order to identify the club convergence phenomenon, the approach developed by Phillips and Sul (2007) is adopted.

This literature adds two main innovations to the literature on CO_2 emissions. First, we conduct a country-specific analysis by focusing on the US. The need to account for country analysis stems from the failure to achieve convergence at a wider and larger scope. In fact the COP21 agreement proposes that member countries adopt a "Nationally Determined Contribution" to CO_2 emissions reduction based on countries specific characteristics, circumstance and nature. This exercise is in sharp contrast to Rios and Gianmoena (2018) who focused on 141 countries. Second, we consider both convergence and club convergence. Existing studies have individually analyses both convergence and club-convergence. In this study, we take a more comprehensive and rigorous approach by examining convergence and club-convergence simultaneously. The club convergence adopted in this study is applied with states in America. This is in contrast to club convergence obtained along regional lines (e.g. Caramero et al., 2014; Morales-Lage et al., 2019 for EU countries).

The choice of the US is based fact that the country is a major emitter of carbon. Statistics show that as of 2013, US's CO_2 emissions in the world with per capita emission of 16.40 metric tons (see Figure-1). The propelling American industrial growth, coupled up with its natural endowment of fossil fuels such as coal reserves (27% of the world's aggregate) besides petroleum and natural gases have led to emissions on a massive scale. The Federal government has expressed deep concerns over the issue in the recent past and commitment to curb CO_2 emissions to 26-28% below 2005 levels by the year 2025(Whitehouse, 2015). Moreover, academics and scholars have also repeatedly voiced the legitimate and reasonable concerns while analysing the dynamics of CO_2 emissions in the USA (see, for instance, Aldy 2006, Payne et al. 2014, Li et al. 2014, Burnett 2016).

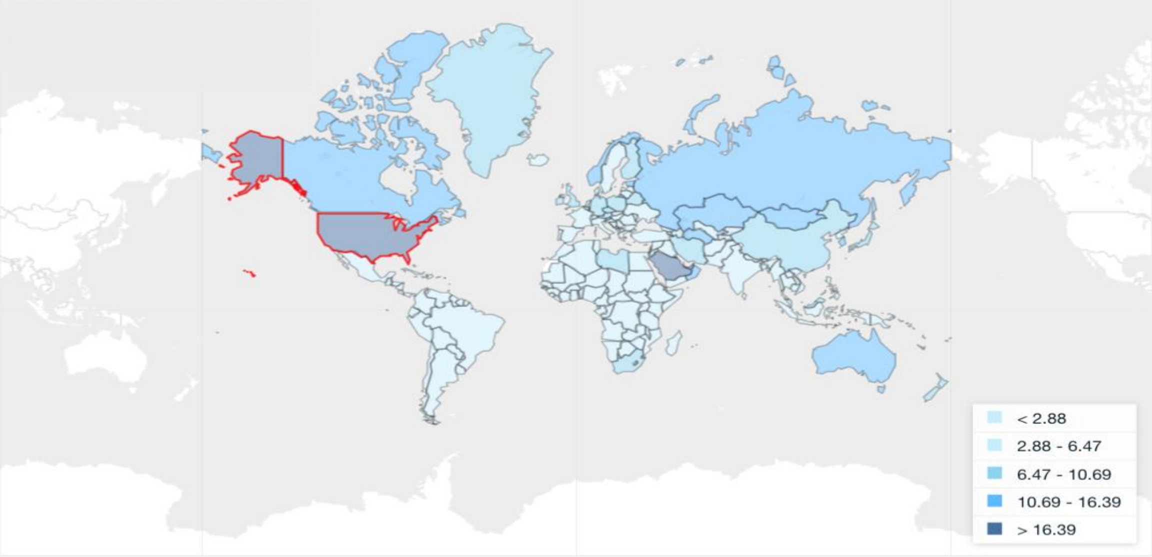

Figure-1. Carbon dioxide (CO_2) emissions around the world in 2013 (in per capita metric tons)
Note: The area highlighted with red borders represents the USA, **Source:** The World Bank

Our key findings suggested that the result of Pesaran's (2007) test depicts an impending state of convergence. The half-life convergence test showed a point estimate of the unbiased half-life of 5.8 years with a 95% confidence interval of 4.8-7.2 years. The KPSS stationary test shows that the null of a unit root is rejected about 70-80% times. Overall, Phillips and Sul's (2007) approach identifies 4 clubs and the rest of the states are put together into another single club, in total five clubs. Concomitantly, these findings have profound implications for the formulation of climate policy based on per capita emissions.

The rest of the paper is structured as follows. The section 2 briefly reflect on the existing evidence on the subject to contextualise the argument and in the existing debate on the subject, section 3 sets out the empirical methodology and data employed as a mean to test the convergence and club convergence in the USA. The section 4 will present the findings which will lead us to conclude in the section 5.

2. Existing Literature on CO_2 Emission Convergence

There are various alternative forms of convergence concepts which have been discussed in the recent literature to unveil CO_2 emissions convergence pattern. The use of convergence concepts such as Beta Convergence (Baumol, 1986), Sigma Convergence (Barro and Sala-i-Martin, 1990; Sala-i-Martin, 1996), Stochastic Convergence (Quah,1990; Quah,1990; Carlino and Mills,1993; Carlino and Mills, 1996), Club Convergence (Apergis and Payne, 2017; Panopoulou and Pantelidis, 2009; Phillips and Sul, 2007) is prevalent in past and recent literature besides several econometric techniques (such as clustering algorithms, cross-sectional and distributional analysis, unit root tests etc.).

The broad base of scholarly contributions is complementary and overlapping in nature; however, an attempt has been made to segregate the studies based on their central themes. The segregation of literature closely follows, Apergis and Payne, (2017). However, a detailed review is presented in this study. The existing evidence on the subject can be classified into two categories. The first strand of literature focuses on the convergence of CO_2 emissions across countries using parametric approaches, most often, using variants of unit root tests. These studies primarily use unit root tests to draw conclusions on the convergence in respective countries. Overall, the literature offers contradicting evidence on the subject. For instance, some studies (Strazicich and List, 2003; Chang and Lee, 2008; Romero-Ávila. 2008; Westerlund and Basher, 2008; Christidou et al., 2013) have argued in favour of stochastic convergence of CO_2 emissions, on the other hand, some studies contradicted (Barassi et al., 2008) and while others have come up with rather mixed and inconclusive results (contrast, for instance, Aldy, 2006; Barassi et al., 2011; Lee and Chang 2008; Yavuz and Yilanci, 2013; Nguyen, 2005; Ezcurra, 2007; Criado and Grether, 2011).

Among the noteworthy studies on the CO_2 convergence, Strazicich and List (2003) employed a panel unit root tests and cross-section regressions on a rich dataset of 21 developed (OECD) countries, their findings suggested that there exists evidence of considerable convergence of CO_2 emissions among the under analysis countries. Their findings were supported by the later study by Chang and Lee (2008) which employed a Lagrange Multiplier (LM) unit root test which also provided significant evidence that CO_2 emissions in the 21 OECD countries converged stochastically when the structural breaks were controlled for. Further support to findings by Strazicich and List (2003) was provided by an empirical study by Romero-Avila (2008) which employed a unit root test using panel stationary test proposed by Lluís Carrion-i-Silvestre (2005). It was concluded that there is a stochastic and deterministic convergence of CO_2 emissions in the sample of OECD countries. A study by Westerlund and Basher (2008) employed an extended data-set of 27 countries from 1870-2002 and employed a Panel unit root test. They reported that report the evidence of CO_2 emissions convergence for the developed and developing countries in the sample set. Their findings were supported by a later study by Christidou et al. (2013) as they employed even a longer data-set ranking from 1870-2006 and used a nonlinear panel unit root test to account for the nonlinearities. They strongly argued for the existence convergence of CO_2 emissions for a sample period of over a hundred years. In a nutshell, the findings of the studies acknowledged in this para are complementary and in a broader sense, they conclude on the presence of CO_2 convergence.

Despite the considerable amount of evidence reported on the convergence of CO_2 emissions by a number of studies acknowledged in the above para, there are also a number of studies which reported contradictory and mixed results. For instance, Barassi et al. (2008) on 21 developed (OECD) countries, employing a panel unit root test reported non-convergence of CO_2 emissions. They critiqued the methodological inaccuracies in the previous studies and attempted to address them (see Barassi, et al., 2008; for details). Similarly, a study by Aldy (2006) employing an Augmented Dickey-Fuller- Generalized least square unit root test, found mixed results. It was reported that although there is evidence of converging CO_2 emissions for the 23 OECD countries, however, on the global scale of 88 countries, the emissions appear to diverge. Perhaps, one implication of the finding was country and development level heterogeneity. Nevertheless, the divergence is not limited to the OECD and None-OECD countries, Lee and Chang (2008) employing at panel seemingly unrelated regressions augmented Dickey-Fuller (SURADF) unit-root tests reported that 14 out of 21 OECD countries exhibit divergence. They argued that these results are more robust than the results of the conventional panel unit root tests. Similarly, Barassi et al. (2011) using a unit root test, Local Whittle estimator and its variants suggested that 13 out of the18 developed countries in their sample exhibit impending signs of convergence. A study by Yavuz and Yilanci (2013) on G-7 countries employed a Threshold Autoregressive (TAR) panel unit root test and which involved splitting the data into two regimes using TAR. Interesting, their results showed the evidence of convergence in the first regime and divergence in the second regime. In evidence from the US and specifically on the regional/states level, a study by Bult (2007) analysing the emissions of Sulphur Dioxides (SO_2) and Nitrogen Oxides (NO_x), they reported stronger evidence of converging emissions rates during the federal pollution control years (1970–1999) than during the local control years (1929–1969). In an earlier study on US List (1999) which was also focusing on SO_2 and NO_2 emissions in 10 US Environmental Protection Agency (EPA) regions reported some convergence. However, in this study we are focusing on Co2 emissions which are a big proportion of GHGs in the US, constituting around 82% of total annual GHG emissions (EPA, 2018).

In terms of empirical approaches to analyse the convergence, there is a strand of literature that employed non-parametric approaches. For instance, a study by Nguyen (2005) employed a rich dataset of 100 industrial countries and Conditional Distribution Estimation and Cross-Sectional Panel Regression. However, reported very limited evidence of CO_2 emissions convergence. Similarly, in another endeavour with even a richer data set (140 countries), a study by Ezcurra (2007) using the Stochastic kernel and Ergodic distribution documented some evidence of reductions in disparities of CO_2 emissions around the world. However, it was argued that such convergences may not persist indefinitely. In another study by Ezcurra (2007b) on 100 countries employing Stochastic Kernel and Ergodic distribution, it was claimed that there is some evidence of CO_2 emissions convergence. Later analysis by Criado and Grether (2011) employed the empirical approach but an extended dataset of 166 countries. They concluded that countries with higher PCE tend to exhibit more divergences. Furthermore, that before the oil price shocks of 1970's the spatial distribution of CO_2 emissions exhibit a flattening, right-skewed and non-stationary pattern. The pattern becomes more stable after the 1970s. In evidence from 25 European countries, a study by Herrerias (2007) employed at Distribution Dynamics and Asymptotic half-life convergence approach. Furthermore, they complemented their analysis by investigating the asymptotic half-life of convergence, mobility indices and the continuous version of the Ergodic distributions. Their results supported the convergence hypothesis among the EU countries although they also observed differences between sub-periods. The existing evidence on the subject discussed in this section is summarised in the following Table-1:-

Table 1: Literature on Cross-country CO_2 emissions

Study	Period	Sample	Methodology	Key Findings
(a) Studies using Unit Root Tests				
Strazicich and List (2003)	1960-1997	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom (UK) and the USA.	Panel unit root tests and cross-section regressions.	The study concludes an evidence of considerable convergence of CO_2 emissions among the sample countries.
Chang and Lee (2008)	1960-2000	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK and USA.	Lagrange Multiplier (LM) unit root test.	The results of the study provide significant evidence that CO_2 emission in the 21 OECD countries convergence stochastically when the structural breaks are controlled for.
Romero-Avila (2008)	1960-2002	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK and USA.	Unit root test using panel stationary test of Lluís Carrion-i-Silvestre (2005).	The results support both stochastic and deterministic convergence of CO_2 emissions over the sample counties.
Westerlund and Basher (2008) [22]	1870-2002	Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Finland, France, Germany, Greece, India, Indonesia, Italy, Japan, Mexico, Netherlands, New Zealand, Peru, Portugal, Spain, Sweden, Switzerland, UK and the USA.	Panel unit root test.	The authors report the evidence of CO_2 emissions convergence for the developed and developing countries in the sample set.
Christidou, Panagiotidis and Sharma (2013)	1870-2006	Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Cuba, Denmark, Ecuador, Finland, France, Germany,	Nonlinear Panel unit root test.	The authors strongly argue convergence of CO_2 emissions for a sample period of over

		Hong Kong, India, Indonesia, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Philippines, Portugal, Spain, Sweden, Switzerland, Taiwan, Thailand, UK, USA and Venezuela.		hundred years.
Barassi, Cole and Elliot (2008)	1950-2002	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and USA.	Panel unit root test.	The study concludes a non-convergence of CO_2 emissions taking into account the methodological inaccuracies in the previous studies.
Aldy (2006)	1960-2000	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK and USA.	Augmented Dickey-Fuller- Generalized least square unit root test.	The study confirms the evidence of converging CO_2 emissions for the 23 OECD countries. However, on the global scale of 88 countries, the emissions appear to diverge.
Lee and Chang (2008)	1960-2000	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK and USA.	Panel seemingly unrelated regressions augmented Dickey-Fuller (SURADF) unit-root tests.	The study reports that 14 out of 21 OECD countries exhibit divergence. The authors argue these results to be more robust over the results of the conventional panel unit root tests.
Barassi et al. (2011)	1870-2004	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Italy, Japan, Netherlands, Norway, Portugal, Spain, Switzerland, Sweden, UK and USA.	Unit root test, Local Whittle estimator and its variants.	The result suggests that 13 out of 18 developed country sample exhibit impending signs of convergence.
Yavuz and Yilanci (2013)	1960-2005	Canada, France, Greece, Italy, Japan, UK and USA.	Threshold Autoregressive (TAR)	The study split the data into two regimes using TAR. The results

			panel unit root test.	show the evidence of convergence in the first regime and divergence in the second regime.
Bulte et al (2017)	1929 to 1999	USA	Minimum LM Unit Root Tests for Stochastic Convergence	Found stronger evidence of converging emission (nitrogen oxides and sulphur oxides) rates during the federal pollution control years (1970–1999) than during the local control years (1929–1969).
List (1999)	1929-1994	USA	Unit Root Tests	The unit root test suggests some convergence in the environmental quality (Sulfur dioxide & Nitrogen Oxides).
(b) Studies using Nonparametric Approaches				
Van Nguyen (2005)	1966-1996	100 industrial countries.	Conditional distribution estimation and cross-sectional panel regression.	The study concludes very limited evidence of CO_2 convergence.
Ezcurra (2007)	1960-1999	140 countries.	Stochastic kernel and ergodic distribution.	The study documents some evidence of reductions in disparities of CO_2 emissions around the world. However, the authors further state that such convergences may not persist indefinitely.

Ezcurra (2007)	1960-1999	87 countries.	Stochastic kernel and ergodic distribution.	The author claims some evidence of CO_2 convergence. In addition, the author also holds per capita income, climatic conditions and trade openness to be essential determinants of CO_2 emissions.
Criado and Grether (2011)	1960-2002	166 countries.	Stochastic kernel and ergodic distribution.	The study concludes that the countries with higher PCE tend to exhibit more divergences. Further, the study also argues that before the oil price shocks of 1970's the spatial distribution of CO_2 emissions exhibit a flattening, right-skewed and non-stationary pattern. The pattern becomes more stable after 1970.
Herrerias (2007)	1920-2007	Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden, UK.	Distribution dynamics and asymptotic half-life convergence approach.	Results support the convergence hypothesis among the 25 EU countries. It was observed that there were differences between sub periods.

While keeping the mixed evidence on the country level studies cited in this section so far, specifically in the subject study we are analysing CO_2 emissions at state-level in the USA. The rationale for doing so is manifested in the earlier discussed importance of USA to the global economy and CO_2 emissions as well as the implications of potential state-level heterogeneity for the climate policy in the USA. Perhaps, the dynamics of CO_2 emissions at state-levels are important to help in the formulation of environmental policy. On this aspect, Auffhammer and Steinhauser (2007) reported that the state-level analysis (disaggregate series and accounting for spatial effects) improved their forecast also helpful in the formulation of environmental policy. As the states with decreasing per capita emissions and a "greener" median voter are more likely to push toward voluntary cutbacks in emissions. Hence, it is vital to consider the convergence of CO_2 emissions at state levels. Nonetheless, we are not only analysing the dynamics of CO_2 emissions and convergence among states of the USA at the national level but also considering the element of club convergence (convergence in the various groups).

3. Methodology

To achieve our objective and to gain a deeper understanding of the convergence, in this study we employed a very novel and rich set of empirical approaches. Our empirical framework entails a number of steps. At first step, we will use Pesaran's (2007) test and Pair-wise approach to test for the Convergence which gives in general what are the rejection frequencies and thus provides evidence of convergence. In the second step, we will adopt the approach of Chi et al (2004) and Donggyu Sul in order to understand estimate the Half-Life to CO_2 emissions convergence using the Panel Dataset. This is one of the contribution of this paper as no previous study on this subject has explored the convergence by employing this approach. In the third step, at the aggregate level, we will use the KPSS test with Fourier transformation as proposed by Becker et al. (2006). The notion is to find out the evidence of a country level convergence as the first two steps are based on panel models. At this juncture we use KPSS test with Fourier transformation on data $y = \ln (CO_2i/avgCO_2i.z)$ i.e., CO_2 of one state (in consideration) is divided by the average value of CO_2 from all states and then we take log value of that ratio for our testing. In the next step, we adopted Club convergence approach Phillips and Sul (2007) and identified club members. The basic reason to do this is that some states may not be converging on average but they may be converging within a group (i.e., in their clubs). Lastly, after we have identified the club members of different clubs we again followed the estimation process discussed in the third step, for each identified clubs in order to deeper understand about the convergence.

3. 1 Methods

Becker et al. (2006)' Fourier stationarity test

This section briefly presents the Becker et al. (2006)' KPSS methodology (more information can be found in Chang et al., 2013). Becker et al. (2006) start from the Kwiatkowski et al. (1992) stationarity test and propose a test that allows for a deterministic seasonality term in the regression, using a Fourier function. As stated above, the Fourier function can account for unknown forms and/or a number of smooth breaks. Different from the well-known Lee and Strazicich (2003) test, pre-specification of the number and form of structural breaks are not prerequisites of this test, as these are controlled by the test through a selected frequency component of a Fourier function. Let us consider the following data generating process (DGP):

$$y_t = a_0 + \beta t + \gamma_1 \sin(2\pi kt/T) + \gamma_2 \cos(2\pi kt/T) + x_t + \xi_t, \tag{1}$$

where the x_t process is described as:

$$x_t = x_{t-1} + \zeta_t, \tag{2}$$

where ξ_t are stationary errors and ζ_t are independent and identically distributed (i.i.d) with variance σ_ζ^2.

Under the null hypothesis ($H_0 : \sigma_\zeta^2 = 0$), the process described by equations (1) and (2) is stationary. The rationale for selecting $[\sin(2\pi kt/T), \cos(2\pi kt/T)]$ as the Fourier expression (where k is the frequency and T is the sample size) is motivated by its ability to approximate absolutely integrable functions to any desired degree of accuracy, where $\gamma = [\gamma_1, \gamma_2]'$ measures the amplitude and displacement of the frequency component, and represents the frequency selected for the approximation.

If $H_0: \gamma_1 = \gamma_2 = 0$, is rejected, the series must have a nonlinear component. In this regard, Testing for the presence of non-linear terms, Becker et al. (2006) propose a F(k) test. However, the distribution of F(k) does not have to be non-standard because of the presence of the nuisance parameter. In this paper, we estimate the critical values for all series used by first generating 10,000 random series under the null of linearity, and thereafter, using the optimum frequency of all actual series to calculate the F-statistic for all of the 10,000 pseudo series. Lastly, the critical values from the sorted vector of the pseudo-F-statistic are obtained. Using this property of equation (2), Becker et al. (2004) develop a test wherein first, one needs to obtain the residuals from the following equations:

$$y_t = a_0 + \gamma_1 \sin(2\pi kt/T) + \gamma_2 \cos(2\pi kt/T) + \varsigma_t \tag{3}$$

and

$$y_t = a_0 + \beta t + \gamma_1 \sin(2\pi kt/T) + \gamma_2 \cos(2\pi kt/T) + \varsigma_t. \tag{4}$$

where equation (3) tests the null of level stationarity, whereas equation (4) tests the null of trend stationarity. The test statistic is given by:

$$\tau_{KPSS} = \frac{1}{T^2} \frac{\sum_{t=1}^{T} \tilde{S}_t(k)^2}{\tilde{\sigma}^2}\ , \tag{5}$$

where $\tilde{S}_t(k) = \sum_{j=1}^{t} \tilde{\varsigma}_j$ and $\tilde{\varsigma}_j$ are the OLS residuals from regressions (3) and (4), respectively. Here, Becker et al. (2006) suggest, similar to the KPSS framework and following the PP-type approach, that a nonparametric estimate of σ^2 can be obtained by choosing a truncation lag parameter l and a set of weights $\varpi_j, j = 1, 2, ..., l.$

$$\sigma^2 = \tilde{\eta}_0 + 2\sum_{j=1}^{l} \varpi_j \tilde{\eta}_j \tag{6}$$

where $\tilde{\eta}_j$ is the j^{th} sample autocovariance of the residuals $\tilde{\varsigma}_t$ from equations (3) and (4), respectively.

In this paper, we follow Carrion-i-Silvestre and Sansó (2006) for the choice of the kernel. On this aspect, for comparing different procedures to establish a boundary rule, Carrion-i-

Silvestre and Sansó (2006) demonstrate that the proposal of Sul et al. (2005) is the best one in terms of size and power. Further, as in Becker et al. (2006), we obtain the frequencies in equations (3) and (4) via the minimization of the sum of squared residuals (SSR). Becker et al. (2006) demonstrate that the loss of power is associated with a large number of frequencies and therefore suggest the use of no more than one or two frequencies. Consequently, we first determine the maximum frequency equal to 5. That is, we estimate the sum of squared residuals for each frequency.

More precisely, in the first step, we estimate equation (3) for each integer k=1,…,5, following the recommendations of Enders and Lee (2012a), who state that a single frequency can capture a wide variety of breaks. A grid-search is performed to find the best frequency, as there is no *a priori* knowledge concerning the shape of the breaks in the data. In the second step, we resort to the stationarity test proposed by Becker et al. (2006), using the obtained best frequency in the first step.

3. 2. Data

The USA CO_2 emissions data on the state level for all the states for the period of 1976-2014 was employed. The choice of time horizon is based on the availability of a balanced panel dataset. The annual data was obtained from the U.S. Energy Information Administration (EIA). The selected timeframe is induced by the availability of data.

4. Analysing and Finding

The starting point of our analysis is to conduct the Pesaran's pair-wise test for CO_2 emissions. To do this, we selected a maximum of 11 lags and show AIC and SBC criteria at 5% and 10% level of significance. Our results are reported based on tests that consider: (i) intercept only; and (ii) intercept and linear trend. These results are presented in Panel A of Table 2.

Table 2: Pairwise Approach to Test Convergence.

Panel A: Below results obtained using Pesaran (2007) Pair-Wise test.								
Maximum Lag-Order was:	11				Maximum Lag-Order was:	11		
Average Lag-Order by AIC:	3.629				Average Lag-Order by AIC:	4.781		
Average Lag-Order by SBC:	1.621				Average Lag-Order by SBC:	1.945		
Case II: An Intercept Only					Case III: An Intercept and a Linear Trend			
	AIC	SBC	AIC	SBC	AIC	SBC	AIC	SBC
ADF	0.288**	0.267**	0.348***	0.347***	0.366**	0.353**	0.457***	0.430***
ADF-GLS	0.146**	0.156**	0.229***	0.246***	0.189**	0.227**	0.262***	0.304***
ADF-WS	0.157**	0.158**	0.214***	0.231***	0.197**	0.206**	0.282***	0.313***
KPSS	0.746**		0.808***		0.541**		0.688***	
Panel B: Results based on approach followed by Choi et al. (2006)								
	No bias corrections	Nickell bias corrected	Time aggregation Bias corrected		Nickell and Time Aggregation bias corrected			
	$\hat{\rho}$	$\hat{\rho}$	$\hat{\rho}$		$\hat{\rho}_{GNTAU}$	$H_{0.025}$	$H_{0.5}$	$H_{0.975}$
Alabama	0.892	0.947	0.815		0.883	4.676	5.584	6.892
Alaska	0.892	0.964	0.833		0.906	5.766	7.033	8.958
Arizona	0.888	0.943	0.806		0.877	4.451	5.274	6.436
Arkansas	0.892	0.95	0.815		0.887	4.798	5.754	7.142
California	0.897	0.947	0.812		0.883	4.716	5.584	6.811
Colorado	0.887	0.947	0.812		0.88	4.524	5.425	6.731
Connecticut	0.888	0.954	0.821		0.89	4.913	5.934	7.443
Delaware	0.899	0.906	0.76		0.827	3.11	3.651	4.391
Florida	0.879	0.936	0.8		0.87	4.191	4.997	6.147
Georgia	0.886	0.923	0.786		0.852	3.713	4.315	5.125
Hawaii	0.886	0.95	0.815		0.887	4.794	5.754	7.152
Idaho	0.894	0.947	0.815		0.883	4.662	5.584	6.922
Illinois	0.895	0.964	0.83		0.903	5.533	6.781	8.699
Indiana	0.892	0.95	0.818		0.89	4.948	5.934	7.368
Iowa	0.885	0.919	0.78		0.845	3.521	4.127	4.958
Kansas	0.889	0.947	0.812		0.883	4.683	5.584	6.877
Kentucky	0.899	0.933	0.795		0.864	4.057	4.747	5.69
Louisiana	0.891	0.961	0.83		0.9	5.398	6.547	8.27
Maine	0.896	0.957	0.824		0.896	5.197	6.329	8.04
Maryland	0.893	0.954	0.821		0.893	5.026	6.125	7.785
Massachusetts	0.896	0.964	0.833		0.906	5.689	7.033	9.142
Michigan	0.892	0.954	0.821		0.893	5.038	6.125	7.759
Minnesota	0.891	0.957	0.827		0.896	5.197	6.329	8.04
Mississippi	0.888	0.954	0.818		0.89	4.938	5.934	7.39
Missouri	0.897	0.968	0.836		0.909	5.861	7.303	9.615
Montana	0.885	0.933	0.797		0.864	4.006	4.747	5.788
Nebraska	0.887	0.94	0.803		0.87	4.217	4.997	6.096

Nevada	0.902	0.926	0.786	0.852	3.687	4.315	5.172
New Hampshire	0.896	0.964	0.833	0.906	5.641	7.033	9.263
New Jersey	0.887	0.954	0.818	0.89	4.911	5.934	7.446
New Mexico	0.888	0.954	0.821	0.893	5.081	6.125	7.663
New York	0.891	0.954	0.821	0.893	5.072	6.125	7.684
North Carolina	0.892	0.943	0.806	0.877	4.372	5.274	6.599
North Dakota	0.884	0.867	0.715	0.777	2.366	2.751	3.262
Ohio	0.883	0.95	0.815	0.883	4.762	5.584	6.721
Oklahoma	0.886	0.954	0.818	0.89	4.933	5.934	7.4
Oregon	0.891	0.954	0.821	0.89	4.932	5.934	7.401
Pennsylvania	0.886	0.95	0.815	0.887	4.825	5.754	7.086
Rhode Island	0.897	0.964	0.83	0.903	5.535	6.781	8.694
South Carolina	0.892	0.957	0.824	0.896	5.216	6.329	7.997
South Dakota	0.889	0.95	0.815	0.887	4.802	5.754	7.134
Tennessee	0.906	0.957	0.824	0.896	5.191	6.329	8.053
Texas	0.894	0.906	0.763	0.83	3.225	3.723	4.379
Utah	0.885	0.947	0.812	0.88	4.518	5.425	6.745
Vermont	0.896	0.964	0.833	0.906	5.685	7.033	9.153
Virginia	0.884	0.943	0.809	0.877	4.403	5.274	6.534
Washington	0.883	0.943	0.806	0.877	4.535	5.274	6.275
West Virginia	0.888	0.957	0.824	0.896	5.245	6.329	7.933
Wisconsin	0.891	0.947	0.815	0.883	4.665	5.584	6.914
Wyoming	0.893	0.968	0.836	0.909	5.928	7.303	9.447

Note: In panel A- (1) Each test is conducted at the 5% significance level. (2) In this code, the critical values are NOT depending on T and lag-order p. (3) Bandwidth for KPSS test is round((T^(1/3))x0.75) (4) **[Fraction of Rejections, based on 5% nominal level tests] (5) ***[Fraction of Rejections, based on 10% nominal level tests]. In panel B – Results reported in this panel are based on the Choi et al (2006) who employed this approach to test PPP convergence oriinally.

Source: Authors' computation. Note: the reason for omitting entries in SBC criteria and KPSS test is that Pesaran test does not report them in their computation

The results of the ADF test shows that the fraction of the rejection of the null hypothesis of unit root is very small. It takes the value of 0.289(0.367) for the intercept (intercept and trend) using the AIC criteria. There is a noticeable decline in the fractions of rejection when ADF-GLS and ADF-WS tests are considered. Overall, the small proportion of the rejection of the null hypothesis points to the fact that PCE, at the state level, is divergent. The high values of fraction of rejection for KPSS test that were estimated to be 0.746(0.541) for the intercept (intercept + trend), further reinforce the evidence of divergence in the sample. Studies whose results are similar to ours include Lee and Chang (2008), Herrerias (2013), and El-Montasser et al. (2015). Further to the above, we calculated the speed of convergence using the Choi et al. (2016) half-life convergence and these are presented in Panel B of

Table 2. This gives information on the time required to eliminate half of the initial gap between actual emissions levels and the steady-state. The advantage of this test is that it overcomes the biases induced by inappropriate cross-sectional aggregation of heterogeneous coefficients, small-sample estimation bias of dynamic lag coefficients, and bias induced by time aggregation (See Choi et al 2006 for details). The results of the half-life estimation for the CO_2 convergence indicates that the duration from 2.75 years (North Dakota) to 7.3 years (Missouri) is required to reduce the level of emission to halve in order to achieve a steady state. The average half-life of convergence was 5.70 with a 95% confidence interval of 5.4 – 5.9 years. This to some extents support earlier results of divergence among PCE at the state level. The closet study to our results is Westerlund and Basher (2008) who obtained half-life convergence to range between 3.1 and 6.1 years for both developing and developed countries.

The next stage of our empirical strategy is to examine KPSS that accounts for Fourier functions. This test is examined for both constant and constant with the trend. Table 3 has these results in two panels namely Panel A and B for constant and trend models respectively.

Table 3: KPSS test with Fourier function results for entire sample

Panel A: The results for Constant with Fourier drift stationarity

	Optimum frequency	Optimum ssr.	Optimum F-stat.	95%	99%	Optimum band	Fourier stat.	95%	99%
Alabama	1	0.0395	22.5079***	3.404	5.465	1	0.101	0.183	0.290
Alaska	1	0.289	18.8008***	3.374	5.355	1	0.225**	0.179	0.326
Arizona	1	0.1478	56.4488***	3.324	5.480	1	0.075	0.182	0.271
Arkansas	1	0.1376	3.3274	3.482	4.996	1	0.096	0.182	0.273
California	1	0.2285	37.5809***	3.173	6.322	3	0.231	0.489	0.669
Colorado	1	0.0202	73.0987***	3.504	5.752	1	0.202**	0.171	0.256
Connecticut	1	0.1447	13.0899***	3.471	5.267	1	0.151	0.165	0.260
Delaware	1	0.4679	40.653***	3.694	6.213	1	0.064	0.179	0.293
Florida	1	0.1151	12.868***	3.419	5.651	4	0.842***	0.511	0.827
Georgia	1	0.0618	40.8632***	3.314	5.661	1	0.024	0.174	0.248
Hawaii	1	0.1664	7.7179***	3.458	5.969	1	0.033	0.169	0.255
Idaho	2	0.2799	8.9681***	3.659	5.595	1	0.438***	0.182	0.283
Illinois	1	0.0846	48.6627***	3.484	5.147	1	0.206**	0.180	0.310
Indiana	2	0.0119	4.1993**	3.293	5.114	1	0.286**	0.185	0.305
Iowa	1	0.1959	17.7594***	3.535	5.473	4	0.269	0.484	0.721
Kansas	1	0.0384	35.4435***	3.575	5.334	2	0.096	0.434	0.700
Kentucky	1	0.0818	26.6459***	3.483	5.927	1	0.104	0.172	0.248
Louisiana	2	0.0768	14.1319***	3.293	5.174	3	0.407	0.472	0.737
Maine	1	0.1979	2.6399	3.019	5.430	1	0.122	0.173	0.255
Maryland	1	0.1373	23.0785***	3.560	5.953	2	0.087	0.410	0.674

Massachusetts	1	0.1919	18.2066***	3.689	5.364	4	0.182	0.451	0.656
Michigan	1	0.0588	9.8012***	3.413	5.051	2	0.139	0.431	0.659
Minnesota	1	0.045	13.7664***	3.324	5.180	1	0.1239	0.182	0.319
Mississippi	1	0.0496	40.8844***	3.265	5.438	1	0.4061**	0.169	0.228
Missouri	1	0.0325	54.337***	3.164	4.855	1	0.0196	0.183	0.270
Montana	1	0.354	12.4944***	3.283	6.402	1	0.056	0.170	0.307
Nebraska	1	0.1246	20.7568***	3.289	5.083	1	0.0529	0.184	0.273
Nevada	1	0.934	23.2356***	3.309	5.589	1	0.1486	0.175	0.297
New Hampshire	1	0.1288	14.8744***	3.582	5.355	2	0.0984	0.434	0.623
New Jersey	1	0.0436	41.1981***	3.622	5.648	1	0.2028**	0.175	0.246
New Mexico	1	0.1045	23.61***	3.628	6.037	1	0.2267**	0.184	0.268
New York	1	0.2925	12.0951***	3.266	5.077	3	0.2835	0.466	0.727
North Carolina	2	0.1203	11.3595***	3.255	5.596	3	0.2917	0.490	0.735
North Dakota	1	1.1367	14.6192***	3.437	5.795	3	1.2936***	0.454	0.655
Ohio	1	0.0716	35.317***	3.544	6.265	1	0.2128**	0.169	0.289
Oklahoma	2	0.0639	0.5146	3.308	5.512	1	0.1614	0.174	0.248
Oregon	2	0.0502	9.7562***	3.210	5.383	1	0.0427	0.171	0.260
Pennsylvania	1	0.0949	21.4255***	3.499	5.091	1	0.1682	0.172	0.280
Rhode Island	1	0.3046	6.722***	3.419	5.946	1	0.0637	0.182	0.302
South Carolina	1	0.0216	42.3941***	3.212	4.980	1	0.1607	0.184	0.266
South Dakota	1	0.0934	9.7278***	3.225	5.266	1	0.0471	0.191	0.275
Tennessee	1	0.1292	6.3823***	3.423	5.101	1	0.1489	0.177	0.249
Texas	1	0.2053	17.9654***	3.319	5.108	3	0.393	0.480	0.756
Utah	1	0.0899	17.0162***	3.220	4.819	1	0.0184	0.182	0.270
Vermont	2	0.1437	2.6929	3.464	5.014	3	0.374	0.436	0.721
Virginia	1	0.0625	2.7048	3.424	5.046	1	0.1469	0.182	0.283
Washington	1	0.1361	20.7089***	3.429	5.717	1	0.165	0.195	0.300
West Virginia	2	0.0513	7.0059***	3.562	6.266	1	0.4194***	0.182	0.256
Wisconsin	1	0.0231	9.0016***	3.428	4.873	1	0.1349	0.162	0.321
Wyoming	1	0.2189	21.5697***	3.373	5.094	2	0.1451	0.4138	0.603

Panel B: The results for Constant and trend with Fourier trend stationarity

	Optimum frequency	Optimum ssr.	Optimum F-stat.	95%	99%	Optimum band	Fourier stat.	95%	99%
Alabama	1	0.0348	19.0763***	3.641	6.123	1	0.040	0.053	0.065
Alaska	1	0.1674	18.8384***	3.593	5.698	1	0.040	0.053	0.067
Arizona	1	0.0702	35.8999***	3.098	5.108	1	0.046	0.056	0.069
Arkansas	1	0.0809	5.5074***	3.513	5.472	1	0.028	0.056	0.070
California	1	0.0205	97.1551***	3.340	5.397	1	0.038	0.056	0.071
Colorado	1	0.012	66.3057***	3.189	4.822	1	0.026	0.054	0.068
Connecticut	1	0.0528	9.2118***	3.187	5.848	1	0.030	0.054	0.068
Delaware	1	0.1365	12.5628***	3.667	5.671	1	0.025	0.057	0.073
Florida	1	0.0353	11.9829***	3.763	5.614	4	0.331***	0.154	0.223
Georgia	1	0.0607	12.704***	3.317	5.068	1	0.025	0.056	0.068
Hawaii	2	0.0996	8.5757***	3.612	5.237	1	0.0362	0.057	0.068
Idaho	1	0.0958	24.6821***	3.382	5.420	1	0.027	0.055	0.070
Illinois	1	0.0244	138.5393***	3.166	5.400	1	0.0422	0.056	0.071
Indiana	2	0.0108	3.0653	3.736	5.439	2	0.0786	0.133	0.194
Iowa	2	0.0321	6.4459***	3.556	5.460	4	0.1024	0.151	0.209
Kansas	1	0.0382	13.8201***	3.362	5.906	2	0.091	0.137	0.199
Kentucky	1	0.0114	5.5247***	3.428	5.324	1	0.0463	0.053	0.068
Louisiana	2	0.0546	12.3429***	3.466	6.072	3	0.133	0.158	0.234
Maine	1	0.1754	4.8093**	3.604	6.343	1	0.0465	0.056	0.070
Maryland	1	0.037	12.19***	3.132	5.016	2	0.0471	0.130	0.184
Massachusetts	2	0.0608	4.2231**	3.319	4.977	4	0.2152***	0.152	0.207
Michigan	1	0.0142	4.8213**	3.333	6.590	2	0.0445	0.136	0.196
Minnesota	1	0.0293	28.5844***	3.338	5.381	1	0.0298	0.057	0.073
Mississippi	1	0.0358	32.4346***	3.682	5.738	1	0.0535	0.056	0.074
Missouri	1	0.0325	50.5816***	3.462	5.289	1	0.0193	0.055	0.068
Montana	2	0.1511	10.043***	3.302	5.249	1	0.0921***	0.054	0.070
Nebraska	1	0.0479	5.1458**	3.412	5.617	1	0.0335	0.054	0.069
Nevada	2	0.0699	3.4032**	3.401	5.239	3	0.2377***	0.153	0.213
New Hampshire	1	0.1176	16.4198***	3.354	5.905	2	0.0505	0.139	0.202
New Jersey	1	0.0324	9.8355***	3.671	6.226	4	0.1512	0.155	0.218
New Mexico	1	0.0638	2.8883	3.370	5.084	4	0.2139***	0.145	0.202
New York	1	0.0373	40.0432***	3.350	4.774	1	0.0247	0.055	0.069
North Carolina	2	0.0331	13.884***	3.550	5.521	3	0.0733	0.152	0.211
North Dakota	1	0.0576	105.6152***	3.594	5.193	1	0.0283	0.055	0.070
Ohio	1	0.0092	122.8591***	3.131	5.921	1	0.0485	0.054	0.068
Oklahoma	1	0.0357	5.9526***	3.405	5.821	1	0.0228	0.056	0.068
Oregon	2	0.0502	8.4455***	3.427	5.052	1	0.0427	0.054	0.070
Pennsylvania	1	0.0181	38.4488***	3.096	5.613	2	0.0687	0.134	0.207
Rhode Island	2	0.2399	10.8406***	3.290	5.156	1	0.0618***	0.055	0.066
South Carolina	1	0.0178	32.7744***	3.279	5.006	1	0.0373	0.054	0.069
South Dakota	1	0.0924	9.7127***	3.066	5.187	1	0.0383	0.054	0.067
Tennessee	1	0.0426	3.097	3.422	5.300	1	0.0391	0.055	0.067
Texas	2	0.0226	15.9083***	3.398	5.295	1	0.1151***	0.055	0.070
Utah	1	0.0899	15.7802***	3.629	5.403	1	0.0184	0.055	0.072
Vermont	1	0.1147	6.8699***	3.305	5.647	1	0.0294	0.054	0.069
Virginia	1	0.0251	15.8909***	3.388	5.536	1	0.0376	0.056	0.074

Washington	1	0.0585	7.7225***	3.399	5.404	1	0.036	0.056	0.071
West Virginia	2	0.0423	6.7081***	3.363	4.778	2	0.1254	0.136	0.207
Wisconsin	1	0.0166	18.2175***	3.198	5.114	1	0.037	0.053	0.069
Wyoming	1	0.052	43.2759***	3.513	5.428	1	0.0514	0.056	0.075

Note: ** denotes rejection of the null hypothesis at 5% level of acceptance. *** denotes rejection of the null hypothesis at 1% level of acceptance.

Source: Authors' computation. Note: the reason for omitting entries in SBC criteria and KPSS test is that Pesaran's test does not report them in their computation

These results presented by employing the KPSS stationary test compliment the earlier results on the stationarity using Pesaran (2007) pair-wise approach. There was a clear indication that the null was rejected for about 70% to 80% times. Further, results based on full sample data (i.e., without club formations) with constant Fourier stationarity test provide evidence that the null hypothesis of stationarity was not rejected for states such as but not limited to Georgia, Hawaii, Montana, Nebraska, Oregon South Dakota and Utah. However, with constant and trend Fourier stationarity test it showed that for Indiana, New Mexico, Tennessee the Fourier based model is an appropriate choice, and the null hypothesis of stationarity is rejected only for Florida, Massachusetts, Montana, Nevada, New Mexico, Rhode Island, Texas indicating that only these states are not convergent. These findings implied that there are state-level heterogeneities for which it would be appropriate to consider the aspect of club convergence. Due to the fact that we have established the existences of two groups, as a result of heterogeneity among the states.

Table 4: Results Based on Club Convergence

Panel A1: Club Convergence Test

Full Sample: Alabama, Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, District of Columbia, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, Wyoming

Beta Coefficient: -0.8208
t-statistics: -18.6026

1st club: North Dakota and Wyoming
Beta Coefficient= 0.192
t-statistics: 3.2

2nd Club: Alsaka, Iowa, West Virginia
Beta Coefficient = 0.012
t-statistics: 0.133
Divergent: Iowa

3rd Club: Indiana, Kentucky, Louisiana, Montana and Nebraska
Beta Coefficient = 0.145
t-statistics: 1.275
Divergent: Kentucky and Montana

4th Club: Alabama, Arkansas, Colorado, Georgia, Illinois, Kansas, Maine, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Mexico, Ohio, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Utah, Wisconsin.
Beta Coefficient = -2.006
t-statistics: -5.640
Divergent: South Dakota and New Mexico

5th Club: Arizona, California, Connecticut, Delaware, Florida, Hawaii, Idaho, Maryland, Massachusetts, Nevada, New Jersey, New York, North Carolina, Oregon, Rhode Island, Vermont, Virginia and Washington.
Beta Coefficient: = 0.143
t-statistics: 1.341

Panel A2: Summary of Club Convergence Test

log(t)	Club1	Club2	Club3	Club4	Club5
Coeff	0.192	0.012	0.145	-0.19	0.143
T-stat	3.2	0.133	1.275	-1.563	1.341

Panel B: Clubs Merging Analysis

New Club 1 **(Club 1 + other convergent clubs)**
Club merging statistics -0.814
(-19.498)
New Club II **(Club 2 + other convergent clubs)**
Club merging statistics -0.795
(-11.754)
New Club III **(Club 3 + other convergent clubs)**
Club merging statistics -0.698
(-11.178)
New Club IV **(Club 4 + other convergent clubs)**
Club merging statistics -0.190
(-1.563)
New Club V **(Club 5 + other convergent clubs)**
Club merging statistics -0.143
(1.341)

Panel C: Clubs Merging Analysis based on Schnurbus et al. (2016)

log(t)	Club1+2	Club2+3	Club3+4	Club4+5

Coeff	-0.273	-0.08	-0.462	-0.698
T-stat	-6.509	-0.698	-5.253	-11.178

Panel D: Final Club Memberships

log(t)	Club1	Club2	Club3	Club4
Coeff	0.192	-0.08	-0.19	0.143
T-stat	3.2	-0.698	-1.563	1.341

Panel D2: Final Club classifications

Club 1: | North Dakota | Wyoming |

Club 2: | Alaska | Indiana | Iowa | Kentucky | Louisiana | Montana | Nebraska | West Virginia |

Club 3: | Alabama | Arkansas | Colorado | Georgia | Illinois | Kansas | Maine | Michigan | Minnesota | Mississippi | Missouri | New Hampshire | New Mexico | Ohio | Oklahoma | Pennsylvania | South Carolina | South Dakota | Tennessee | Texas | Utah | Wisconsin |

Club 4: | Arizona | California | Connecticut | Delaware | Florida | Hawaii | Idaho | Maryland | Massachusetts | Nevada | New Jersey | New York | North Carolina | Oregon | Rhode Island | Vermont | Virginia | Washington |

Source: Authors' Computations

Notes: Testing for the one-sided null hypothesis $\hat{b} \geq 0$ against $b<0$, the analysis makes use the critical value $t_{0.05;\, rT-2-1=228} = -1.65156$ across all cases. Statistical significance at the 5% level is denoted by 'a', rejecting the null hypothesis of convergence. The figures in parenthesis denote t-statistics.

Results of the club-convergence are presented in Table 4. Essentially, we examined five different clubs/subgroups, which consist of 2, 3, 5, 22 and 18 countries, respectively. A formal test of convergence would give answers to inquires whether we can merge clubs to form a larger convergence, on the one hand, and also give general information on each club. It is presented in Table 4 that there is convergence in club one member states (North Dakota and Wyoming). These states are similar in terms of socio and economic fundamentals such as GDP per capita, population density, and geographical locations. Thus, it could be argued that the PCEs are high and not be too different from each other. This is due to the fact that North Dakota is an oil-producing state, while Wyoming fracking is celebrated for its large oil and mining sites. Hence, both states would converge towards steady states in the long run. The speed of convergence is estimated to be one-fifth of the average of the full sample's speed. We proceed to inquire if the rest group forms the other convergent club. The significance of the t- statistics shows that we can repeat the clustering procedures. This procedure would continue until the t-statistics for the repeated clustering is no longer significant. The second club convergence has three member countries (Alaska, Iowa and West Virginia). These states economic activities revolves around agriculture. Iowa could be regarded to have diverging tendencies due to their higher in population density, income (GDP per capita). Alaska and West Virginia are among the lowest GDP level and GDP growth. The speed of convergence of this club is somehow low. This might be attributed to the fact that the club has representatives of both convergence and divergence tendencies.

The third club membership includes Kentucky, Indiana, Louisiana, Montana and Nebraska. These states economic activities is a mix of both agricultural, manufacturing and industrial. It could be argued that these countries are related in terms of median income level (GDP per capita), and housing units. However, it could be deduced that Montana and Kentucky are divergent from this club. This could be due to the fact that the level of industrialization is relatively low (for instance, Kentucky is famous for its distillery industry, while Montana is widely known as cattle ranching). Thus, these diverging states could be due to low carbon emissions. Another plausible reason for this could be related to higher population in Kentucky, which is estimated to be about four folds of Montana's. Also, the population growth rate in the former is twice that of the latter (United States Census Bureau). It is worthy to note that the GDP of Kentucky is almost 5 times that of Montana's. The fourth club majorly consists of states with relatively high income, high population and population density. The economic activities of these states are majorly manufacturing and services (retail) with less emphasis on agriculture. The manufacturing activities include automobile, shipping docks, aeroplanes, fabrics, rug and carpet mills, pharmacy, to mention a few. Also, this group has several iconic companies that are listed in the Fortune 1000 companies. However, of this group, it was discovered that South Dakota and New Mexico have diverging tendencies, a situation attributable to their means of economic activities (agriculture). Hence, their level of emission is considered to be low. Further scrutiny into these states shows that (i) they have relatively low income and GDP per capita; (ii) lower population and population density, and (iii) lower housing units. The rest of the states belongs to the fifth club. These states economic activities are hugely centred on services, which covers financial, fashion, sport, sport, hospitality, civil service and tourism. Also, states house the manufacturing of computers and other ICT gadgets. Of this lot, it was found that Maryland, New Jersey, Oregon and Rhode Island behave in a different manner. This might be due to their different level of economic activities. For instance, Rhode Island derives her income from Marinas and ship-building. Also, prior to the millennium, Oregon is a natural resource centred state (fishing, timber and agriculture). Perhaps, there is a renewed attempt to shift the economy to the high tech sector, which started receiving attention in the early 2000s. For instance, to know whether we can merge club 1 with any other clubs, we can use the log t-test with a panel that contains information of all member clubs. If it was found that the estimated convergence parameter (beta) is significant, which indicates convergence, we can conclude that the clubs can be merged. This iteration continues until the points where the convergence parameter is no longer statistically significant. The results presented in Table 4 prima facie evidence of the rejection of the null hypothesis of convergence. This leads us to conclude.

5. Conclusion

This paper examines the convergence hypothesis for 50 states in the United States of America for the period 1976-2014. In essence, we seek to examine whether per capita carbon emission across the states moves in the same direction and converge over time or there are tendencies towards divergence. The two techniques used to test out hypothesis are Pesaran (2007) panel unit root test and Phillips and Sul's (2007) tests. The advantages of these two approaches are that they can capture the effect and/or significance of the heterogeneity that might be inherent in the dataset. Furthermore, these tests have been identified to be very flexible to cover a range of transition periods.

Our results support the existence of divergence at the state level of carbon emission in the USA. Using the half-life convergence method, we were able to report a point estimate of the unbiased half-life of convergence. Although, we found that there were significant differences among states on the time it takes to converge, however, the average among the states was 5.7 years with a 95% confidence interval of 5.4 – 5.9 years. The results of stationarity using the KPSS stationary test complimented and hence provided robustness to our estimates by suggesting that the null of a unit root was rejected most of the time. The notion of the club convergence which was also a significant contribution of this study was also tested. The results showed that there were four identifiable clubs. The rest of the states are put together into another single club, making a total of five clubs. The estimates and classifications of the club convergence and corresponding clubs are particularly important in terms of harmonisation and formulations of climate policies at state and federal levels.

The half-life estimates are also important in terms of policy formulation on CO_2 emissions and coordinated actions by the states to influence the convergence and homogeneity of policy in the Post-convergence epoch. Evidence of divergence from the USA would make it difficult for other developed or developing countries to agree to emissions reduction obligations. These diverging tendencies require special consideration from policymakers. There is a need for policymakers in the US to be aggressive in terms of setting policies that would seek to achieve convergence, while simultaneously reducing PCE. If this can be achieved, other developed countries will follow suit and encourage developing countries to also reduce their emission level. Also, the attainment of convergence will enhance the accuracy of future projection of the emission rate.

The results of the club-convergence test have demonstrated the importance of streamlining emission abatement policies to emission convergence paths that is unique to the clusters of states. Hence, the state-specific structure must be considered when designing and implementing policies that seek to mitigate emissions, so that some states would not be adversely affected due to the influence and actions of other states. Concomitantly, a common federal level policy for all the states under investigation may not be very efficient due to the heterogeneity among them. Undauntedly, there is a need to cut down on unsustainable energy use and carbon emissions at a global level which also requires technology transfer and domestic innovations. In this regards, the actions and policies at the national or federal levels require to be matched with states and international levels. On the states levels, the aspect of convergence and club convergence covered in this treatise has profound implications which can be a good guide to navigate the federal policy and match it with global efforts to tackle the environmental challenges.

The transparency and quality of direct GHG emissions have not been significantly improved over time and it had been acknowledged in forums that energy-intensive organisations in the USA decreased the transparency, it is proposed the future research shall incept this aspect.

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