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# Conditional convergence in per capita carbon emissions since 1900

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## HIGHLIGHTS

- We study conditional convergence in relative per capita carbon dioxide.
- We use recently developed RALS-LM unit root test procedures.
- Our sample of 44 countries dates back to the beginning of the 20th century.
- We reject the null hypothesis of unit root in relative per capita carbon dioxide emissions.

## ARTICLE INFO

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## ABSTRACT

This study examines conditional convergence in relative per capita carbon dioxide emissions by using the recently developed Residual Augmented Least Squares-Lagrange Multiplier (RALS-LM) unit root test procedure that allows for endogenously determined structural breaks. Utilising a sample of 44 developed and developing countries dating back to the beginning of the 20th century, the null hypothesis of a unit root in relative per capita carbon dioxide emissions is soundly rejected, lending support to the conditional convergence hypothesis. Also, an examination of the pre and post-World War II suggests that convergence in relative per capita carbon dioxide emissions is more pronounced over the post-World War II period as opposed to the pre-World War II period.

## 1. Introduction

The growing concern over climate change has led to significant discussions within the policy and academic circles. On the policy front, since the conclusion of the Framework Convention on Climate Change in 1992, there have been ongoing commitments to stabilize and reduce emissions of greenhouse gases, which would otherwise continue to influence global warming and climate change [1,2]. The Kyoto Protocol also led to a range of new policies designed to restrict greenhouse gas emissions on a global scale. However, a critical issue confronting the adopted policies relates to the feasibility of proposed mitigation strategies, especially with regards to the allocation of emission obligations across countries. This issue has led to the emergence of different allocation proposals mostly centred on country characteristics with regards to emissions [3–5].

Along these lines, it has been argued that the acceptance of per capita emission allocation strategies depends on the divergence or convergence of per capita emissions across countries. For instance, in the presence of divergence, per capita emission allocation strategies would result in the relocation of emissions-intensive economic activities or a substantial resource transfers through international trading of carbon allowance. However, in the presence of per capita emission convergence, countries are more likely to endorse emission allocation strategies as the concern of relocation and resource transfer may be of lesser importance [6,7]. As Ordás Criado and Grether [6] argue, per capita emissions across countries appear to have stabilised, although total emissions have increased. Consequently, evidence of convergence in national per capita emissions (compared to absolute level) targets may be a more acceptable basis for political compromises amidst major international negotiations on climate change.

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In understanding trends and distributional patterns of pollutants, the reliance on evidence of convergence has fuelled a growing literature devoted to investigating the convergence of per capita emissions, especially per capita carbon dioxide ($CO_2$) emission across countries.[1] This literature (referred to as environmental convergence) which is relatively new, was initially investigated by Strazicich and List [9] who examined convergence in $CO_2$ emissions on a sample of OECD countries, although an earlier study by List [10] examined convergence in other pollutants among US regions. However, recent empirical evidence has produced mixed results as some studies suggest convergence (see, e.g., [11,9,12] while others suggest divergence (see, e.g., [13]).

Our paper makes an important contribution to the literature by examining conditional (or stochastic) convergence in relative per capita $CO_2$ emissions using an extended sample of countries and time period. Empirical studies examining convergence in $CO_2$ emissions use a relatively short time span dating back to the 1960s. Exceptions include Westerlund and Basher [12], Herrerias [14] and Christidou et al. [15], which explore relatively longer time spans dating back to 1920. However, these studies are limited in terms of the countries covered. For instance, Herrerias [14] focuses only on 25 EU-countries while Westerlund and Basher [12] and Christidou et al. [15] focus on 28 and 36 countries respectively.

The existing literature (discussed in Section 2) examining global convergence either focuses on a large number of countries over a short period, or a small number of countries over a relatively longer period. Ultimately, our study differs from previous empirical works by investigating a broader range of developed and developing countries as well as a longer period, thus providing a comprehensive and historical analysis of stochastic convergence across 44 countries over the period 1900–2014. Therefore, we bridge the gap in the literature by considering a historical perspective and examine stochastic convergence by applying methods that build on Strazicich and List [9] which allows for one or two endogenous structural breaks in level and trend of the series.

Our study is related to a small strand of the environmental convergence literature pioneered by Strazicich and List [9], although we focus on a global sample instead of a sample of OECD countries, and adopt empirical approaches that deal with the bias against rejecting a false unit root null hypothesis as discussed in the literature. In addition, it has been argued that ADF-type unit root tests which do not allow for structural breaks lead to bias results, lending support to empirical procedures which allow for exogenous or endogenous structural breaks.[2]

As a result, our preference is to utilise the Lagrange Multiplier (LM) unit root test which builds on Strazicich and List [9] and allows for one or two endogenous structural breaks in the level and trend. In examining the convergence hypothesis, the LM unit root test has the added advantage of exploiting both the time-series and cross-sectional information available in our dataset on per capita $CO_2$ emissions while allowing for structural breaks in the series to study the convergence hypothesis (see [17]).

Our study also adopts the newly developed Residual Augmented Least Squares-Lagrange Multiplier (RALS-LM) unit root tests of Lee et al. [18] accommodating for trend-breaks. Some notable merits of this method over alternative approaches to measuring unit roots are evident. For instance, given that structural changes may be present in the series, especially regarding trend-shifts, the tests can control for their effects. Unlike the usual LM and other unit root tests, the transformed LM tests are only dependent on the number of trend-shifts but not on the location of breaks. Consequently, these new empirical procedures are free from additional nuisance parameters. Furthermore, these new tests utilize the information of non-normal errors by combining the RALS procedure of Im and Schmidt [19] and Meng et al. [20] to improve the power of the unit root tests.[3]

The estimated results based on the RALS-LM test procedure suggest that the null hypothesis of unit root in relative per capita $CO_2$ emissions is rejected at the 5% level of significance for all countries (with the exception of Italy). An examination of the LM test results also indicates that the null hypothesis of unit root is rejected at 5% level for 40 countries and at 10% level for three countries. These results indicate conditional convergence in relative per capita $CO_2$ emissions since the beginning of the 20th century. In addition, we assess the evolutionary path of convergence for the pre-and post-World War II time periods and find evidence of divergence over the pre-WWII period and convergence over the post-WWII period. This result implies that the evolutionary path differs over historical periods and that the resurgence of globalisation over the post-WWII period is more pronounced.

The remainder of the paper is structured as follows. Section 2 presents a brief overview of the relevant literature. Section 3 presents the dataset and empirical methodology used in the analysis. Section 4 reports and discusses the empirical results. Section 5 concludes with policy recommendations.

## 2. Overview of related literature

Empirical studies on environmental convergence adopt three main approaches to examine per capita $CO_2$ convergence across countries. These include the $\beta$-convergence approach, $\sigma$-convergence approach and the conditional (or stochastic) convergence approach. The specification of $\beta$-convergence focuses on testing a linear trend between initial level of pollution and the growth rate of per capita emissions across countries. Here, a negative sign on the coefficient of initial per capita emissions is interpreted as evidence of convergence across countries [9]. $\beta$-convergence is a necessary condition for the second approach used in the literature which is the specification of $\sigma$-convergence. $\sigma$-convergence considers the intra-distributional behaviour and dynamics of a cross-section of countries [13,22] and follows the original idea of $\sigma$-convergence described in Barro and Sala-i-Martin [23] but translates into a decrease in the cross-section variance of per capita emissions over time [24,25].

Strazicich and List [9], Nguyen Van [22], Aldy [13], Panopoulou and Pantelidis [26], Brock and Taylor [27] and Jobert et al. [28] are among the studies that examine $\beta$- and $\sigma$-convergence in various cluster of countries as well as in global samples across various periods. Strazicich and List [9] presents the first study that examines cross-country convergence in $CO_2$ emissions. Focusing on a balanced panel of 21 OECD countries for the period 1960–1997, the authors find evidence of stochastic and $\beta$-convergence. Using a cross-sectional regressions analysis which tests for $\beta$-convergence, they find that per capita emissions have converged conditional on the prices of gasoline and the average winter temperature. Similarly, Brock and Taylor [27] focusing on OECD countries over the period 1960–1999 and find evidence of unconditional and conditional $\beta$-convergence. Aldy [13], on other hand, tests for $\sigma$-convergence in a sample of OECD countries as well as a global sample. Evidence from this study suggests divergence in the global sample but convergence in the OECD sample. This finding of divergence for the global sample is consistent with Nguyen Van [22] who also examine both $\beta$- and $\sigma$-convergence, as well as

[1] The wide focus on $CO_2$ emissions compared to other greenhouse gases is mainly because of its major contribution to atmospheric concentrations. Specifically, $CO_2$ contributes more than 70% of atmospheric concentrations and nearly 30 billion tonnes is released into the atmosphere each year as a result of day-to-day human activities [8].

[2] Nonetheless, this empirical approach has also been criticised in the literature (See, for example [16]).

[3] As noted by Payne et al. [21] the presence of non-normal errors does not affect standard unit root tests but the utilization of the information on non-normal errors should not be ignored. Hence, the RALS procedure provides a convenient way to increase the power of the standard unit root tests and utilize important components of a time series.

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