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New evidence on the convergence of per capita carbon dioxide emissions from panel seemingly unrelated regressions augmented Dickey–Fuller tests

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ABSTRACT

Using the data for per capita carbon dioxide (CO_2) emissions relative to the average per capita emissions for 21 countries in the organisation for economic co-operation and development (OECD) covering the period 1960–2000, this paper seeks to determine whether the stochastic convergence and β-convergence of CO_2 emissions are supported in countries with the same level of development. In other words, are shocks to relative per capita CO_2 emissions temporary in industrialized countries? We respond to this question by utilizing Breuer et al.'s [Breuer JB, McNown R, Wallace MS. Misleading inferences from panel unit-root tests with an illustration from purchasing power parity. Review of International Economics 2001;9(3):482–93; Breuer JB, McNown R, Wallace MS. Series-specific unit-root tests with panel data. Oxford Bulletin of Economics and Statistics 2002 64(5):527–46] panel seemingly unrelated regressions augmented Dickey–Fuller (SURADF) unit-root tests, which allow us to account for possible cross-sectional effects and to identify how many and which members of the panel contain a unit root. Our empirical findings provide evidence that relative per capita CO_2 emissions in OECD countries are a mixture of I(0) and I(1) processes, in which 14 out of 21 OECD countries exhibit divergence. The results reveal that conventional panel unit-root tests can lead to misleading inferences biased towards stationarity even if only one series in the panel is strongly stationary.

1. Introduction

Many observers believe that the ever-growing world energy consumption will result in greater carbon dioxide (CO_2) emissions and global warming. The Kyoto Protocol hence requested that countries which had ratified its set of rules need to reduce their emissions of CO_2 and five other greenhouse gases, compared to 1990 levels.[1] Thus, when we consider this issue in the context of a climate protection policy, it becomes clear that global CO_2 emissions should be reduced significantly and per capita emissions should gradually move toward further convergence [1]. Nevertheless, the relationships among economic development, environmental protection, and energy consumption are closely bound up together.[2] How, then, can one restrain the excessive opportunity cost from the promotion of an environmental protection policy? It is hence very important that we pay attention to understanding whether per capita CO_2 emissions exhibit the properties of stationarity for the convergence of all countries which enforce environmental protection.[3]

The environmental convergence hypothesis has recently been the subject of growing research interest across countries. For what reason, then, can we not neglect this phenomenon? We respond to this by noting that if per capita CO_2 emissions present the I(1) process, then the shocks affecting the series will have permanent effects. If per capita CO_2 emission series exhibit an I(0) process, then the effects of the shock are merely transitory, making the need for policy action only slightly mandatory. Our motivation for this paper is to examine the stochastic convergence hypothesis and determine whether shocks to time paths of per capita CO_2 emissions relative to the average per capita emissions (hereafter "relative per capita CO_2 emissions") are permanent or temporary. If relative per capita CO_2 emissions are trend stationary, then it follows that the emission series will return to its mean or trend

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[1] The main greenhouse gases include CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), PFCs (petrofluorocarbons), HFCs (hydrofluorocarbons), and SF_6 (sulphur hexafluoride).

[2] The topics have been extensively investigated in recent decades, for instance, Kraft and Kraft [35]; Yang [36]; Lee and Chang [37] and Altinay and Karagol [38].

[3] Stationarity implies that probability laws controlling a process are stable over time. Series that are non-stationary in levels have a unit root. Shocks change the long-run level of the series permanently (see Ref. [32]).

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path over time.[4] However, stochastic convergence is a necessary but not sufficient condition for conditional convergence. Thus, we supplement the tests for stochastic convergence with additional β-convergence tests to determine whether conditional convergence is occurring.

Since panel data can provide us with much more information and increase the power of unit-root tests, our paper attempts to describe the achievements and contributions of economic development and the environment by applying a recent panel unit-root test, the seemingly unrelated regressions augmented Dickey–Fuller (SURADF) test, which was developed by Breuer et al. [2,3]. The panel SURADF test provides several advantages, such as exploiting the information from the error covariance and allowing for the autoregressive process, i.e., the estimation permits for heterogeneity in the lag structure across the panel members. It also allows us to identify how many and which members of the panel contain a unit root [4]. Such a modus has already been used extensively in the study of macroeconomics and international finance up to now. However, to date, from the point of view of energy and the environmental agenda, we do not find any panel SURADF test that has been applied. Moreover, there have been only a few attempts made to apply panel data unit-root tests to relative per capita CO_2 emissions. To the best of our knowledge, only Strazicich and List [5] and Nguyen-Van [6] used panel data to test for stochastic convergence, but their findings are not robust, because they failed to address the issue of cross-sectional dependence.[5] O'Connell [7] showed that ignoring the contemporaneous correlation represented by non-zero off-diagonal elements may result in a test with severe size distortions.[6]

Convergence in relative CO_2 emissions implies that countries are not following independent paths in pollution control, but are collectively moving towards a common standard of environmental performance. A definition of stochastic convergence, attributable to Carlino and Mills [8,9], is that the log of relative (to that of the overall economy) per capita CO_2 emissions is trend stationary.[7] We also consider the extended settings from List [10], Strazicich and List [5], Nguyen-Van [6], Aldy [11] as well as Romero-Avila [12] in discussing the convergence of per capita CO_2 emissions relative to average per capita emissions. Carlino and Mills [9] suggested that the time-series test for convergence is useful in examining the dynamic path of the relative variables. List [10] used two indicators of air pollutant emissions to investigate whether environmental quality has stochastically converged across the USA during the period 1929–1994. He found that poorer regions have not had to trade off environmental quality for their relative gains in income levels.

Aldy [11], in employing the Elliott et al. ([13], DF-GLS) unit-root test, also found little evidence that countries's relative per capita CO_2 emissions are converging. In addition, Nguyen-Van [6] used non-parametric methods to examine the convergence in relative CO_2 emissions per capita for a sample of 100 countries covering the period from 1966 to 1996, and reported that industrialized countries exhibit a convergence pattern, but found little evidence of convergence for the overall sample. Strazicich and List [5] combined both cross-sectional and time-series tests for convergence using a dataset of per capita CO_2 emissions relative to the average per capita emissions for 21 industrial countries over the period 1960–1997. In both tests, the null hypothesis that emissions have diverged was strongly rejected. In addition, after analyzing the time-series behavior of US CO_2 per capita among various states, Aldy [14] presented strong evidence of no convergence in this series over the period 1960–1999 using conventional panel unit-root tests.

It has been argued that conventional univariate unit-root tests not only fail to consider information across countries, but are also restricted in regard to the problem of small samples, thereby leading to less efficient estimations [15]. However, a common feature of the panel tests mentioned above is that they maintain the null hypothesis of a unit root in all panel members. Therefore, their rejection indicates that at least one panel member is stationary, with being no information regarding how many series, or which ones, are stationary [2,16]. Moreover, Sarno and Taylor [17] pointed out that the conventional types of panel unit-root tests are biased towards stationarity if only one series is strongly stationary.[8] This possibility for a mixed panel implies that some of the countries may be stationary while others may be non-stationary. As such, how to apply a suitable test approach to understand the characteristic of the series is a very important assignment.

When compared with the conventional wisdom, which neglects the use of relative data and instead uses level data, it is found that such studies are unable to inquire into the convergence phenomenon, because they merely indicate whether the CO_2 emissions are stationary or not. More importantly, such an approach might give rise to some biases. For instance, first of all, the univariate unit root combines the problem with small samples and low power, and secondly, the traditional panel unit-root tests are not robust, because they fail to address the issue of cross-sectional dependence. Our results provide a possible explanation for the mixed results arising from the panel unit-root test, because only a few cases dominate the panel results in our sample countries. When the extant panel unit-root test is performed, the rejection of the null that all series have a unit-root is not sufficiently informative regarding which series are stationary under the alternative. The unit-root test of the panel SURADF, however, addresses this shortcoming.

According to the Kyoto Protocol, developed countries are expected to take the lead in preventing global climate change, even though in less than 20 years developing countries will likely surpass them as the main emitters of CO_2. The overall picture shows that one of the developed countries is leading in terms of total CO_2 and CO_2 per capita. Thus, in recalling past attempts to control energy usage and from the prospects of further energy policies for CO_2 emission reductions, this article provides a comprehensive overview of the shock to CO_2 emissions that could lead to fluctuations in energy-related CO_2 emissions which are used as a policy instrument.

[4] List [10] indicated that stochastic convergence implies that the effects of temporary shocks dissipate over time, and likewise that the time series does not possess a unit root. List [10] and our paper mainly focus on the contribution to the debate regarding the environmental convergence hypothesis, but nevertheless, different from List [10] who investigates the air pollutant emissions, CO_2 emissions are the principal issue in our manuscript. Aside from this, List also uses univariate unit-root tests to analyze the sample of US regions, and we discuss the case of 21 OECD countries by panel unit-root tests. Clearly, the target and the main story are different between the List's paper and our works.

[5] Carrion-i-Silvestre et al. [39] developed panel stationarity tests with multiple structural breaks (also see Ref. [40]). However, given that the panels are stationary without structural breaks, introducing multiple breaks will reduce the power of the panel data unit-root tests [41].

[6] However, for small samples, he reported an empirical size slightly exceeding 0.5 for values of severe size biases close to unity.

[7] In addition, a vast number of papers discussed the stationarity of per capita CO_2 emissions in level for OECD countries. Nevertheless, because this does not constitute the main focus of our paper, we only emphasize the concept of stochastic convergence herein.

[8] Breuer et al. [2] argued that when an *F*-statistic rejects the null hypothesis that a vector of coefficients is equal to zero by analogy to a simple regression, it is not necessarily true that each coefficient is non-zero. Likewise, when the unit-root null hypothesis is rejected, it may very well not be justified to assume that all series in the panel are stationary.