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STOCHASTIC CONVERGENCE OF PER CAPITA GREENHOUSE GAS EMISSIONS AMONG G7 COUNTRIES: AN EVIDENCE FROM STRUCTURAL BREAKS

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Abstract
This paper tests the stochastic convergence hypothesis of per capita greenhouse gas emissions among G7 countries over the period from 1990 through 2014. In testing stochastic convergence, we transfer per capita greenhouse gas emissions in level, relative to the average by using methodology of Carlino and Mills (1993, 1996) and investigate unit root properties of these obtained relative series by using recently developed unit root test of Narayan and Popp(2010) besides conventional unit root tests. Conventional unit root test results indicate that stochastic convergence hypothesis is supported only for France and United States. On the other hand, when we take into account existence of possible structural breaks, the results provide significant support for stochastic convergence of relative per capita greenhouse gas emissions for France, Japan, United Kingdom and United States and divergence for Canada, Germany and Italy.

Keywords: *Stochastic convergence, divergence, greenhouse gas emissions, unit root, structural breaks*
Jel Classification: *B40, C22*

1. INTRODUCTION

The effects of greenhouse gases which trap heat in the atmosphere increase and contribute mainly to the global climate change and the greenhouse effect. The gases, namely carbon dioxide, methane, oxygen, nitrogen, hydrochlorofluorocarbons, chlorofluorocarbons, sulfur hexafluoride etc. are the main cause of global warming and each of them remain in the atmosphere for different amounts of time, ranging from a few years to thousands of years. It is assumed that human activities are responsible for almost all of the increase in these

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greenhouse gases. The Kyoto Protocol which is the main international agreement enforced in 2005, has targets for ratified nations to reduce their greenhouse gas emissions (Kyoto Protocol, 1997).

In this sense, testing stochastic convergence hypothesis of greenhouse gas emissions has received great attention for energy economists, policy makers and researchers. To test convergence and/or divergence hypothesis, most of the studies in the literature use relative carbon dioxide emissions as the important greenhouse gas emission with the longest life cycle, existing in the atmosphere around a hundred years [Strazicich and List(2003), Nguyen-Van(2005), Aldy(2006), McKitrick and Strazicich(2005), Ezcurra(2007), Barassi et al.(2008), Chang and Lee(2008), Lee et al. (2008), Romero-Avila(2008), Westerlund and Basher(2008), Bimonte(2009), Nourry(2009), Panopoulou and Pantelidis(2009), Herrerias(2013), Li and Lin(2013), Yavuz and Yilanci(2013), Wang et al.(2014), Hao et al.(2015)]. The results of these studies differ based on considered countries, time periods and methodologies.

This paper examines the stochastic convergence hypothesis of per capita greenhouse gas emissions among G7 countries for the period 1990-2014. In order to test stochastic convergence, we follow methodology of Carlino and Mills (1993, 1996) and transfer per capita greenhouse gas emissions in level, relative to the average for each considered countries. Then, the null hypothesis that per capita greenhouse gas emissions are diverging is tested. In other words, we test unit root null hypothesis in the logarithm of the ratio of per capita greenhouse gas emissions relative to the average as discussed in data and empirical results section. If the unit root null hypothesis cannot be rejected, it means that there is evidence against stochastic convergence of per capita greenhouse gas emissions. By contrast, a rejection of the unit root null hypothesis supports stochastic convergence.

As a difference of this paper, we use Narayan and Popp(2010) unit root test which is flexible enough to allow for at most two structural breaks in the level and trend, in addition to conventional unit root tests. Considering structural breaks is important because these breaks could be the result of changes in the degree of environmental control legislation, changes in the political system and/or energy price fluctuations, etc. Besides that, based on historic experience of the countries, such factors as environmental policy and the occurence of an energy crisis may cause exogenous shocks in terms of greenhouse gas emissions reductions (Stern et al., 1996). In the light of these considerations, by finding structural breaks, it is possible to discover critical economic activities which cause greenhouse gas emissions to fluctuate in G7 countries.

The remaining of the paper is constructed as follows: The next section presents the unit root test methodology of Narayan and Popp(2010), the third section describes data and reports empirical results. Finally, the last section concludes the paper.

2.METHODOLOGY

In this paper, the stochastic convergence hypothesis is tested for per capita greenhouse gas emissions of G7 countries by using recently developed Narayan and Popp (2010) unit root test which can identify two structural breaks in the level and trend. Since the paper of Perron(1989) which argues that the exclusion of structural breaks while modeling the unit root often leads to accepting the false null hypothesis, many authors addressed this issue by identifying structural breaks endogenously and exogenously. The tests which consider breaks endogenously include Zivot and Andrews(1992), Lumsdaine and Papell(1997) and Lee and Strazicich(2003,2004). However, Poop(2008) noticed that spurious regression arises from different interpretations of test parameters under the null and alternative hypothesis, because of the parameters affect the selection of the break date. This problem is solved by Narayan and Popp(2010). Following Schmidt and Philips (1992), they developed an ADF type test for the case of innovational outlier (IO) where the data generating process is constructed as an unobserved component model. The data generating process of a time series y_t is considered as follows:

$$y_t = d_t + u_t \qquad (2.1.1)$$

$$u_t = \rho u_{t-1} + \varepsilon_t \qquad (2.1.2)$$

$$\varepsilon_t = \psi^*(L)e_t = A^*(L)^{-1}B(L)e_t \quad ; \quad e_t \sim iid(0,\sigma_e^2). \quad (2.1.3)$$

Here, d_t is deterministic component and u_t is a stochastic component. $A^*(L)$ and $B(L)$ are the lag polynomials. It is assumed that the roots of these lag polynomials which are of order p and q, respectively, lie outside the unit circle.

This test considers two different specifications for trending data: One specification allows for two breaks in the level (denoted M1) and the other specification allows for two breaks in level and trend (denoted M2). These model specifications (M1 and M2) differ in deterministic component d_t. For M1, d_t is defined as follows:

$$d_t^{M1} = \alpha + \beta t + \psi^*(L)(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t}) \qquad (2.1.4)$$

And also d_t which is defined for M2 can be seen in below:

$$d_t^{M2} = \alpha + \beta t + \psi^*(L)(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} + \gamma_1 DT'_{1,t} + \gamma_2 DT'_{2,t}) \quad (2.1.5)$$

In both specifications, $DU'_{i,t}$ and $DT'_{1,t}$ are defined as follows, respectively:

$$\begin{aligned} DU'_{i,t} &= 1(t > T'_{B,i}) \qquad ; \; i = 1,2 \\ DT'_{i,t} &= 1(t > T'_{B,i})(t - T'_{B,i}) \; ; \; i = 1,2. \end{aligned} \qquad (2.1.6)$$

Here $T'_{B,i}$, $i = 1,2$ describe the true break dates, θ_i and γ_i parameters indicate the magnitude of the level and trend breaks, respectively. The inclusion of ψ^* in corresponding equations enables breaks to occur slowly over time. Specifically, it is assumed that the series responds to shocks to the trend function the way it reacts to shocks to the innovation process e_t (Vogelsang and Perron, 1998).

In testing unit root hypothesis for M1 and M2, the IO-type test regression can be derived by merging the structural model (2.1.1)-(2.1.5). The test equation for M1 is as follows:

$$\begin{aligned} y_t^{M1} &= \rho y_{t-1} + \alpha_1 + \beta^* t + \theta_1 D(T'_B)_{1,t} + \theta_2 D(T'_B)_{2,t} \\ &+ \delta_1 DU'_{1,t-1} + \delta_2 DU'_{2,t-1} + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + e_t \end{aligned} \qquad (2.1.7)$$

with $\alpha_1 = \psi^*(1)^{-1}\left[(1-\rho)\alpha + \rho\beta\right] + \psi^{*'}(1)^{-1}(1-\rho)\beta$; $\psi^*(1)^{-1}$ being the mean lag, $\beta^* = \psi^*(1)^{-1}(1-\rho)\beta$; $\phi = \rho - 1$; $\delta_i = -\phi\theta_i$ and $D(T_B^{'})_{i,t} = 1(t = T_{B,i}^{'} + 1)$, $i = 1, 2$.

The test equation for M2 can be written as below:

$$y_t^{M2} = \rho y_{t-1} + \alpha^* + \beta^* t + \kappa_1 D(T_B^{'})_{1,t} + \kappa_2 D(T_B^{'})_{2,t} + \delta_1^* DU_{1,t-1}^{'} + \delta_2^* DU_{2,t-1}^{'} + \gamma_1^* DT_{1,t-1}^{'} + \gamma_2^* DT_{2,t-1}^{'} + \sum_{j=1}^{k} \beta_j \Delta y_{t-j} + e_t \qquad (2.1.8)$$

where $\kappa_i = (\theta_i + \gamma_i)$, $\delta_i^* = (\gamma_i - \phi\theta_i)$ and $\gamma_i^* = -\phi\gamma_i$, $i = 1, 2$.

In order to test the null hypothesis of a unit root ($H_0 : \rho = 1$) against the alternative hypothesis ($H_1 : \rho < 1$), Narayan and Popp(2010) use t-statistics of $\hat{\rho}$, denoted $t_{\hat{\rho}}$, in Equations (2.1.7) and (2.1.8). They claim that critical values of the test, assuming unknown break dates, converge with increasing sample size to the critical values when break points are known. Therefore, this test identifies the breaks more accurately than the earlier structural break tests. Further, breaks in trend and levels are allowed in both null and alternative hypotheses. The detailed information on identifying the timing of the breaks and critical values can be found in Narayan and Popp(2010).

3. DATA AND EMPIRICAL RESULTS

This paper uses annual per capita greenhouse gas emissions (GHG) for G7 countries over the period from 1990 through 2014. The source of the data is Organisation for Economic Co-Operation and Development (OECD) statistics database. In testing stochastic convergence, we use Carlino and Mills' (1993, 1996) methodology to convert data into the relative per capita greenhouse gas emissions. Following their methodology, we calculate a yearly sample average for considered G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom and United States) and then compute the natural logarithm of relative per capita greenhouse gas emissions for each country i as follows:

$$y_t^i = \ln(\mathrm{GHG}_{PC_t}^i \big/ average\,\mathrm{GHG}_{PC_t})$$

where $\mathrm{GHG}_{PC_t}^i$ is the per capita greenhouse gas emissions for country i and $average\,\mathrm{GHG}_{PC_t}$ is the average value of G7 countries in the sample period. The obtained relative per capita greenhouse gas emissions are labelled for Canada, France, Germany, Italy, Japan, United Kingdom and United States as **LCANADA**, **LFRANCE**, **LGERMANY**, **LITALY**, **LJAPAN**, **LUK** and **LUS**, respectively.

We start testing stochastic convergence hypothesis of per capita greenhouse gas emissions among G7 countries by using conventional ADF (Dickey and Fuller, 1979), PP (Philips and Perron, 1988), DF-GLS (Elliott et al.,1996) and NP (Ng and Perron, 2001) unit root tests. The results of these unit root tests are tabulated in Table 1.

Table 1: The results of conventional unit root tests

Series	ADF	PP	DF-GLS	NP (MZa)
LCANADA	-1.6997(0)	-1.6998(0)	-1.6676(0)	-3.9888(0)
LFRANCE	-3.7725(0)**	-3.8444(2)**	-3.8478(0)***	-10.5004(0)
LGERMANY	-1.6140(0)	-1.6141(0)	-1.2935(0)	-1.1220(0)
LITALY	1.1276(0)	1.7611(2)	-0.0445(0)	0.2703(0)
LJAPAN	-1.2319(0)	-1.3984(2)	-1.4633(0)	-4.4340(0)
LUK	-2.2138(0)	-2.0924(1)	-2.5871(0)	-9.2351(0)
LUS	-4.9527(1)***	-2.8852(8)	-4.8052(1)***	-40.5379(1)***

Notes: **** and ** indicate rejection of the unit root null hypothesis at the 1% and 5% significance levels, respectively. The numbers in paranheses are the lag orders in the ADF and DF-GLS tests. The lag parameters are selected on the basis of Schwarz (SC) criterion. The truncation lags for the Newey-West correction of the PP and NP tests are in parantheses. The NP test is based on MZa statistic*.

The results in the table indicate that the relative per capita greenhouse gas emissions series for Canada, Germany, Italy, Japan and United Kingdom have a unit root based on all considered ADF, PP, DF-GLS and NP unit root tests. On the other hand, there is evidence of stationarity for the relative per capita greenhouse gas emissions series of France and United States. According to these conventional unit root tests results, it can be concluded that the stochastic convergence hypothesis is supported only for France and United States. Since Perron(1989) argues that ignoring a structural break can lead to false acceptance of the unit root null hypothesis, we extend our analysis by taking into account existence of possible structural breaks in the relative per capita greenhouse gas emissions. For this purpose, we apply a new unit root test proposed by Narayan and Popp (2010) which is flexible enough to allow for at most two structural breaks in the level and trend. The obtained results based on M1 (breaks in level only) and M2 (breaks in level and trend) specifications are reported in Table 2.

Table 2: The results of Narayan and Popp (2010) unit root test with two structural breaks

	M1				M2			
Series	**Test statistic**	**TB_1**	**TB_2**	**k**	**Test statistic**	**TB_1**	**TB_2**	**k**
LCANADA	-1.816	2000	2004	0	-1.926	2000	2006	0
LFRANCE	-2.312	1997	2008	0	-6.083***	1999	2008	0
LGERMANY	-2.112	2005	2007	0	-4.222	2000	2007	3
LITALY	-0.096	1995	1997	0	-2.024	1995	2008	0
LJAPAN	-1.905	1997	2007	0	-6.706***	2000	2006	3
LUK	-3.495	2000	2002	0	-5.203**	2001	2008	1
LUS	-4.714**	2002	2006	1	-5.019*	2002	2006	1

Critical values for Narayan and Popp (2010) unit root test

	1%	**5%**	**10%**
For M1	-5.259	-4.514	-4.143
For M2	-5.949	-5.181	-4.789

Notes: **** , ** and * indicate rejection of the unit root null hypothesis at the 1%, 5% and 10% significance levels, respectively. TB_1 and TB_2 are the dates of the structural breaks, k is the lag lenght. Critical values are obtained from Narayan and Popp (2010).*

The test results of M1 specification give that the relative per capita greenhouse gas emissions series show unit root properties for all considered countries except United States. On the other hand, the results of M2 specification indicate that there is evidence of stationarity for the relative per capita greenhouse gas emissions series of France, Japan, United Kingdom and United States. These results with identified mixed structural breaks, provide significant support for stochastic convergence of relative per capita greenhouse gas emissions for France, Japan, United Kingdom and United States and divergence for Canada, Germany and Italy.

4. CONCLUSION

This paper investigates the stochastic convergence hypothesis of per capita greenhouse gas emissions among G7 countries over the period from 1990 through 2014. For this purpose, we obtain relative per capita greenhouse gas emissions following Carlino and Mills (1993, 1996) and apply recently developed unit root test of Narayan and Popp(2010) in addition to conventional unit root tests. The obtained results from conventional unit root tests show that stochastic convergence hypothesis is supported only for France and United States. On the other side, the results of Narayan and Popp(2010) unit root test give significant evidence for stochastic convergence of relative per capita greenhouse gas emissions for France, Japan, United Kingdom and United States.

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