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Research Article/Araştırma Makalesi

The Convergence in Greenhouse Gas Emissions Across G-7 Countries

G-7 Ülkelerinde Sera Gazı Emisyonu Yakınsaması

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Abstract

Environmental degradation, such as climate crisis, global warming, etc., is one of the crucial issues for countries. Studies in the literature analyze the convergence in environmental degradation regarding the environmental convergence hypothesis using different indicators such as carbon dioxide emissions, ecological footprint, etc. to identify the differences in environmental quality across countries. This study tests the environmental convergence hypothesis for G-7 countries over the period 1997-2018. To do so, we use greenhouse gas emissions per capita as an indicator of environmental degradation and apply non-linear dynamic factor model developed by Phillips & Sul (2007). According to the results, countries do not converge to a single equilibrium point. However, Phillips & Sul (2007) convergence methodology allow us to identify possible convergence clubs. The club clustering algorithm identifies three convergence clubs, each converging to a different steady-state. Club 1, which converges to higher greenhouse gas emissions per capita level, includes Canada and United States, whereas Club 2 includes Germany and Japan, and Club 3 includes France, Italy, and the United Kingdom. The results confirm that the that the environmental convergence hypothesis does not hold for G-7 countries.

Jel Codes: *EO, Q5, CO*
Keywords: *Convergence Hypothesis, Environmental Convergence Hypothesis, Greenhouse Gas Emissions, Log-t test, G-7 Countries*

Öz

İklim krizi, küresel ısınma gibi çevresel bozulmalar ülkeler için en önemli konulardan biridir. Literatürdeki çalışmalar, ülkeler arasındaki çevresel kalite farklılıklarını ortaya koymak için karbondioksit emisyonları, ekolojik ayak izi gibi farklı göstergeler kullanarak çevresel yakınsama hipotezi çerçevesinde çevresel bozulmadaki yakınsamayı incelemektedir. Bu çalışma, 1997-2018 döneminde G-7 ülkeleri için çevresel yakınsama hipotezini test etmektedir. Bunu yapmak için, çevresel bozulmanın bir göstergesi olarak kişi başına düşen sera gazı emisyonları kullanılmakta ve Phillips & Sul (2007) tarafından geliştirilen doğrusal olmayan dinamik faktör modelini uygulanmaktadır. Ede edilen bulgulara göre ülkeler tek bir denge noktasına yakınsamamaktadır. Bununla birlikte, Phillips & Sul (2007) yakınsama metodolojisi, olası yakınsama kulüplerinin belirlenmesini sağlamaktadır. Kulüp kümeleme algoritması, her biri farklı bir sabit duruma yakınsayan üç yakınsama kulübü tanımlamaktadır. Kişi başına daha yüksek sera gazı emisyonları seviyesine yakınsayan Club 1, Kanada ve Amerika Birleşik Devletleri'ni içerirken, Kulüp 2 Almanya ve Japonya'yı ve Kulüp 3 Fransa, İtalya ve Birleşik Krallık'ı içermektedir. Elde edilen sonuçlar çevresel yakınsama hipotezinin G-7 ülkeleri için geçerli olmadığını doğrulamaktadır.

Jel Kodları: *EO, Q5, CO*
Anahtar Kelimeler: *Yakınsama Hipotezi, Çevresel Yakınsama Hipotezi, Sera Gazı Emisyonu, Log-t Test, G-7 Ülkeleri*

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1. Introduction

Environmental degradation issues are discussed widely in the literature. Many studies investigate the relationship between environmental degradation and other indicators such as economic growth, globalization, trade openness, and other institutional variables, etc. Besides, in recent years, several studies have focused on the environmental convergence hypothesis. The subject of convergence[3] in the literature has arisen from the neoclassic growth model developed by Solow (1956), which assumes that under the assumption of diminishing returns, countries with similar structural characteristics and technologies will converge to the same equilibrium over time. The empirical literature mainly concentrates on the three hypotheses: the absolute, the conditional, and the club convergence. The absolute convergence states that the per capita incomes of countries converge to one another in the long-run, independently of their initial conditions. However, the hypothesis of conditional convergence assumes that incomes of countries with similar structural characteristics, such as, public policies, technologies, etc.) converge to one another in the long-run, independently of their initial conditions. Lastly, the hypothesis of club convergence indicates that per capita incomes of countries that have similar structural characteristics converge to one another in the long-run, provided that their initial conditions are similar as well (Galor,1996; Jan & Chaudhary, 2011; Rodrik, 2011). Besides, the convergence framework can be classified as the β-convergence and σ-convergence. The β-convergence identifies the partial correlation between the initial level of income and growth in income over time. However, there is σ-convergence if the distribution of real income per capita among economies decreases in time (Young et al., 2008).

As mentioned above, in recent years, several studies have focused on the environmental convergence hypothesis by using different ecological indicator, econometric methodology, and sample. The environmental convergence hypothesis states that although initially, developing countries experience higher environmental degradation than more developed countries, and differences in the quality of their environments diminish over time. In other words, environmental convergence occurs since countries with low emissions per capita tend to increase their level of emissions whereas countries with high emissions per capita tend to decrease their level of emissions, resulting in a catch-up in pollutants emissions per capita. (Brock & Taylor, 2003; Lawson et al., 2020).

Convergence in environmental indicators (or emissions in per capita terms) across countries may be important for several reasons. For example, convergence in per capita emissions may affect the negotiating process of multilateral climate agreements (Aldy, 2006; Acar et al., 2018). Furthermore, countries with lower per capita emissions expect countries with higher per capita emissions to make more effort toward mitigating climate change (Aldy, 2006). If there is no convergence in emissions, the principle of forcing equal per capita emissions may result in significant international transfers of rents through carbon allowance trading or the relocation of pollution-intensive industries (Acar et al., 2018). Testing convergence in ecological indicators may help researchers and policymakers to develop more effective and efficient policies. It can be said that policies considering countries converging in terms of

[3] See Islam (2003) for a survey on the convergence concept.

environmental quality could be more successful than those considering a more heterogeneous group of countries in terms of environmental quality (Bilgili & Ulucak, 2018; Yilanci et al., 2022).

Studies investigating the environmental convergence hypothesis use different indicators such as carbon dioxide emissions and ecological footprint. While numerous studies use carbon dioxide emission, recent studies use ecological footprint as an indicator of environmental degradation due to ecological footprint being a comprehensive indicator. Ecological footprint, introduced by Wackernagel & Rees (1998), consists of six components which are named carbon footprint, forest footprint, grazing land footprint, built-up land footprint, fishing grounds footprint, and cropland footprint (Erdogan & Okumus, 2021: 2). Besides, the importance of greenhouse gas emissions is emphasized in the Kyoto Protocol. Therefore, the aims to reduce environmental degradation are related to not only carbon dioxide emissions but also greenhouse gas emissions per capita, including CO_2, methane (CH_4), nitrous oxide (N_2O), and perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfur hexafluoride (SF_6). Based on the convergence hypothesis, this study aims to investigate convergence in greenhouse gas emissions per capita across the Group of Seven (G-7) countries, Canada, Germany, France, Italy, Japan, the United Kingdom, and the United States, over 1997-2018. There are three reasons why we focus on G-7 countries. First, in 2019, the total gross domestic product of the G-7 countries was $37.43 trillion (at constant 2015 values). In other words, G-7 countries have 44.5% of the global gross domestic product in 2019 (United Nations Statistics Division, 2021). Second, G-7 countries, as developed economies, historically had contributed to climate change through economic growth. However, these countries have more resources to fix the damage of the environmental problem at the same time. Lastly, it can be said that these countries are the most powerful countries to struggle with greenhouse gas emissions by using necessary technology and implementing appropriate policies (El Montasser et al., 2015: 6544; Solarin et al., 2021).

Within this context, this study analyzes the convergence in greenhouse gas emissions per capita across G-7 countries over the period 1997-2018 using the club convergence methodology of Phillips & Sul (2007). This study contributes to the existing literature are two-fold. First, although there are numerous studies on the convergence process of carbon dioxide emissions and ecological footprint, this is one of the few studies to test the convergence process of greenhouse gas emissions. Second, our study focuses on the G-7 countries, which is rarely used in the environmental convergence literature.

In the next part of the study, we summarize the empirical literature on convergence in environmental degradation. Then, we present the data set and econometric method. Section 4 presents the results. Finally, Section 5 concludes.

2. Literature Review

Numerous studies in the literature analyze the environmental convergence hypothesis, using various environmental degradation indicators. It is observed that the literature on the environmental convergence hypothesis follows three paths regarding the environmental degradation indicator: (i) studies using carbon dioxide emissions, (ii) studies using the ecological footprint, and (iii) studies using greenhouse gas emissions.

The first group of studies use carbon dioxide emissions as a proxy indicator of environmental degradation. For instance, Van (2005) tests the convergence process of carbon dioxide emissions for 100 countries over 1966-1996 using non-parametric methods. The findings support the existence of beta convergence across countries. Aldy (2006) tests the convergence of CO_2 emissions across OECD and other 88 countries over 1960-2000 using the Dickey-Fuller test methodology. The results show that there is a weak convergence across countries. Ezcurra (2007) tests the convergence in carbon dioxide emissions across 87 countries over 1960- 1999 using a non-parametric approach. The findings identify those cross-country differences of carbon dioxide emissions per capita decrease. Avila (2008) investigates the stochastic and deterministic convergence in carbon dioxide emissions among 23 industrialized economies over 1960 to 2002 using the panel stationary test. The results show that there is strong evidence supporting the convergence process across countries. Westerlund & Basher (2008) investigate the convergence in CO2 emissions for developed and developing countries over 1870 to 2002 using the panel unit root tests method. According to the results, there is stochastic convergence across countries. Panopoulou & Pantelidis (2009) test the convergence in carbon dioxide emissions among 128 countries over 1960-2003 using the club convergence method. According to the results, there is convergence in carbon dioxide for the full sample. Runar et al. (2017) tests the convergence in carbon dioxide emissions across 124 countries over 1985-2010 using parametric and non-parametric methods. The results support that beta convergence for the full sample. Ahmed et al. (2017) tests the convergence process CO_2 emissions across 162 countries for the period 1960-2010 using the Wavelet unit root test approach. The findings support the existence of stochastic convergence for 38 countries. Tiwari & Mishra (2017) test the convergence in CO_2 emissions across 18 Asian countries for the period 1972-2010 using parametric and non-parametric tests. The results show that there is β and α convergence across countries. Churchill et al. (2018) test the convergence process of carbon dioxide emissions in 44 countries over 1900-2014 using RALS-LM unit root tests. The results show that there is conditional convergence across countries. Different from other studies, some studies test the convergence in carbon dioxide emissions for sectors. For instance, Wang & Zhang (2014) investigate beta convergence and stochastic convergence in carbon dioxide emissions per capita for the period 1996-2010 for six sectors among 28 provinces in China using panel unit root tests. The findings indicate that there is convergence across 28 provinces for all sectors. Similarly, Braännlund et al. (2014) investigate the convergence process of carbon dioxide emission intensity across 14 industrial sectors in Sweeden over 1990-2008. The results support the beta convergence of carbon dioxide intensity among sectors. Some studies analyze the convergence across different regions such as Acaravcı & Erdogan (2016). They conclude that there is divergence across 7 world regions over 1960-2011 using CADF test. Some studies such as Robalino-Lopez et al. (2016) use carbon dioxide intensity across South African countries over 1980-2010 using log-t test method. The results show that there is no convergence pattern as a whole. Emir et al. (2019) tests the convergence process CO_2 emissions intensity among 28 EU countries over 1990-2016 using log-t test method. The findings show that there is club convergence across countries. Solarin

& Twari (2020) analyze the convergence in SO_2 emissions across 32 OECD countries over 1850-2005 using Fourier PANKPSS method. The results show that there is convergence in SO_2.

The second group of studies focus on ecological footprint as an indicator of environmental degradation. For instance, Bilgili & Ulucak (2018) analyze the convergence in ecological footprint across G-20 countries for the period 1961-2014 using log-t test and panel KPSS test methods. The results show that there is stochastic and deterministic convergence among countries. Ulucak et al. (2020) examine the convergence process ecological footprint across 23 sub-Saharan countries over 1961-2014 using club convergence approach. The results show that there are several convergence clubs for each component of ecological footprint. The results support the existence of five convergence clubs. Similarly, Apaydin et al. (2021) test the convergence in ecological footprint across 130 countries. The findings show that there are five clubs. Erdogan & Okumus (2021) analyze the convergence of ecological footprint for the period 1961-2016 in different countries using panel stationary test and log-t methodology. The results show that there are several convergence clubs across countries. Tillaguango et al. (2021) test the convergence process ecological footprint in Latin America over 1990 to 2016 using log-t test method. The results show that there are three convergence clubs. Ursavas (2021) test the convergence in ecological footprint across 50 African countries over 1970-2019 using log- t test approach. According to the findings, there are four convergence clubs.

The third group of studies use greenhouse gas emissions as a proxy for environmental degradation. Some of these studies such as de Oliveira & Bourscheidt (2017), Wu et al. (2019), Apergis & Garzon (2020), Ivanovski & Churchill (2020) test the convergence across regions. Oliveira & Bourscheidt (2017) test the convergence of per capita greenhouse gas emissions in 39 sectors of 40 countries over 1999 to 2007. Wu et al. (2019) focus on 30 provinces of China over 2007-2016 using spatial methods. The results show that there is no beta and sigma convergence in greenhouse gas emissions in the whole country. Apergis & Garzon (2020) test the convergence process greenhouse gas emissions among 19 Spain regions for the period of 1990-2017 using the Phillips-Sul methodology. The results indicate that there are four clubs. Ivanovski & Churchill (2020) test the convergence process three greenhouse gas emissions-carbon dioxide, nitrous oxide, and methane emissions among regions in Australia over 1990 to 2017. The results identify multiple convergence clubs. The results show that there is a convergence in CO_2 for the agriculture, food, non-durable goods manufacturing, and services sectors. However, the studies such as Montasser et al. (2015) focus on the convergence across G-7 countries. Montasser et al. (2015) test the convergence of greenhouse gas emissions across G7 countries over 1990 to 2011 using the pairwise test method. The results do not support the convergence among countries.

3. Data and Methodology

The dataset covers G-7 countries (United States, United Kingdom, Japan, Italy, France, Germany, Canada) over 1997 to 2018. Greenhouse gas emissions per capita by countries are obtained from World Bank. Greenhouse gas emissions per capita are which are defined as emissions divided by the total population of countries, measured in tonnes of carbon dioxide equivalents, and include the emissions of CO_2, CH_4, N_2O, SF_6, HFC, and PFC.

Panel A in Table 1 shows the descriptive statistics of greenhouse gas emissions per capita data for the initial and final year. The findings show that there is a decrease in greenhouse gas emissions levels between 1997 and 2018. The standard deviation of the greenhouse gas emissions per capita indicates that disparities in terms of greenhouse gas emissions per capita across countries have decreased. Panel B in Table 1 shows the greenhouse gas emissions per capita values of countries for the initial and final years. The data indicates that France has the lowest values of greenhouse gas emissions per capita in 1997 and 2018, respectively. However, United States has the highest values of greenhouse gas emissions per capita in 1997 while Canada has the highest values 2018.

Table 1: Descriptive Statistics

Panel A								
Full Panel	**1997**				**2018**			
	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
	0.014	0.006	0.008	0.024	0.010	0.005	0.006	0.019
Panel B								
Countries	**1997**				**2018**			
Canada	0.0214				0.0195			
France	0.0084				0.0063			
Germany	0.0127				0.0097			
Italy	0.0087				0.0066			
Japan	0.0101				0.0093			
United Kingdom	0.0122				0.0068			
United States	0.0244				0.0183			
Skewness: 0.8316; Kurtosis: 2.1248; Jarque-Bera Prob:0.0000								

In this study, in order to analyze convergence in greenhouse gas emissions per capita we follow the club convergence methodology developed by Phillips & Sul (2007). The Phillips & Sul (2007) methodology, which is based on a nonlinear time-varying factor model, is the decomposition of panel data for a total number of environmental-related patents, (X_{it}), into two components:

$$X_{it} = g_{it} + a_{it} \quad (1)$$

where g_{it} is a systematic component and $a_{it}$is a transitory component. To separate common components from idiosyncratic components, we transform Equation 1 as follows:

$$X_{it} = \left(\frac{g_{it}+a_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t \quad (2)$$

where μ_t and δ_{it} present the common component and idiosyncratic component, respectively. δ_{it} measures the distance between the common trend component μ_t and X_{it}. Since it is impossible to directly estimate the loading coefficients, δ_{it}, without imposing additional structure, the common factor may be removed by constructing the following relative transition paths:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \tag{3}$$

where h_{it} indicates the relative transition parameter which measures the loading coefficient δ_{it} to the panel average at time t. Equation (3) presents the two properties of h_{it}. First, the cross-sectional mean of h_{it} is equal to one. Second, if the factor loading coefficients δ_{it} converge to δ_i, the relative transition parameter h_{it} converges to one. In this case, Equation (4) represents that the cross-sectional variance of the relative transition parameter, H_t, converges to zero asymptotically. The property $H_t \rightarrow 0$ is used to test the null hypothesis of income convergence and to group provinces into convergence clubs.

$$H_t = N^{-1} \sum_{i=1}^{N} (h_{it} - 1)^2 \rightarrow 0 \text{ as } t \rightarrow \infty \tag{4}$$

To test the convergence hypothesis, Phillips & Sul (2007) introduce the following log-t regression model:

$$\log\left({}^{H_1}/_{H_T}\right) - 2log[\log(t)] = \alpha + blog(t) + u_t \text{ (5) for } t = [rt], [rt]+1, \dots., T \text{ with } r > 0 \tag{5}$$

where $[rt]$ represents the initial observation in the regression, which indicates that the first fraction of the data is discarded. Phillips & Sul (2007) propose setting r = 0.3 when the sample is small (T ≤ 50), based on Monte Carlo simulations. Phillips & Sul (2007) introduce a conventional inferential procedure for Equation (5). Specifically, they recommend a one-sided t-test with heteroskedasticity and autocorrelation-consistent standard errors. The null hypothesis of convergence is rejected if $t_b < -1.65$.

4. Results

Table 2 shows the results of the log-t test for greenhouse gas emissions per capita. The findings indicate that the null hypothesis of panel convergence of greenhouse gas emissions per capita is rejected at a 5% level of significance. Therefore, there is not convergence to the same equilibria for the period of 1997-2018 among G-7 countries.

Table 2: Log *t* Test Results (G-7 Countries)

Variable	Coefficient	Standard Error	T-Statistics
Greenhouse gas emissions per capita	-0.9205	0.0070	-131.5495

Notes: the null hypothesis of convergence is rejected with the D-stat is smaller than -1.65.

The null hypothesis of convergence in the full panel is rejected, but there could be convergence clubs that converge to different equilibria. The club clustering algorithm might be used to determine convergence clubs within the panel. Thus, we follow the clustering procedure to indicate possible convergence clubs. The findings show that there are three convergence clubs that converge to a different constant. These clubs consist of 2, 2, and 3 countries, respectively.

Table 3: Final Clubs

Clubs	Countries	Coefficient	T-Statistics
Club 1	Canada | United States	-0.975	-0.825
Club 2	Germany | Japan	3.163	8.429
Club 3	France | Italy | United Kingdom	1.441	6.799

We use the club merging tests procedure (Phillips & Sul, 2009) to analyze whether there are any merged cluster clubs into larger clubs due to the club clustering algorithm overestimate the clubs. The results show that there is no merge of clubs in Table 4.

Table 4: Test of Club Merging

Clubs	Coefficient	T-Statistics
Club 1+2	-0.414	-12.510
Club 2+3	-1.556	-21.319

Figure 1: Relative Transition Paths of Clubs

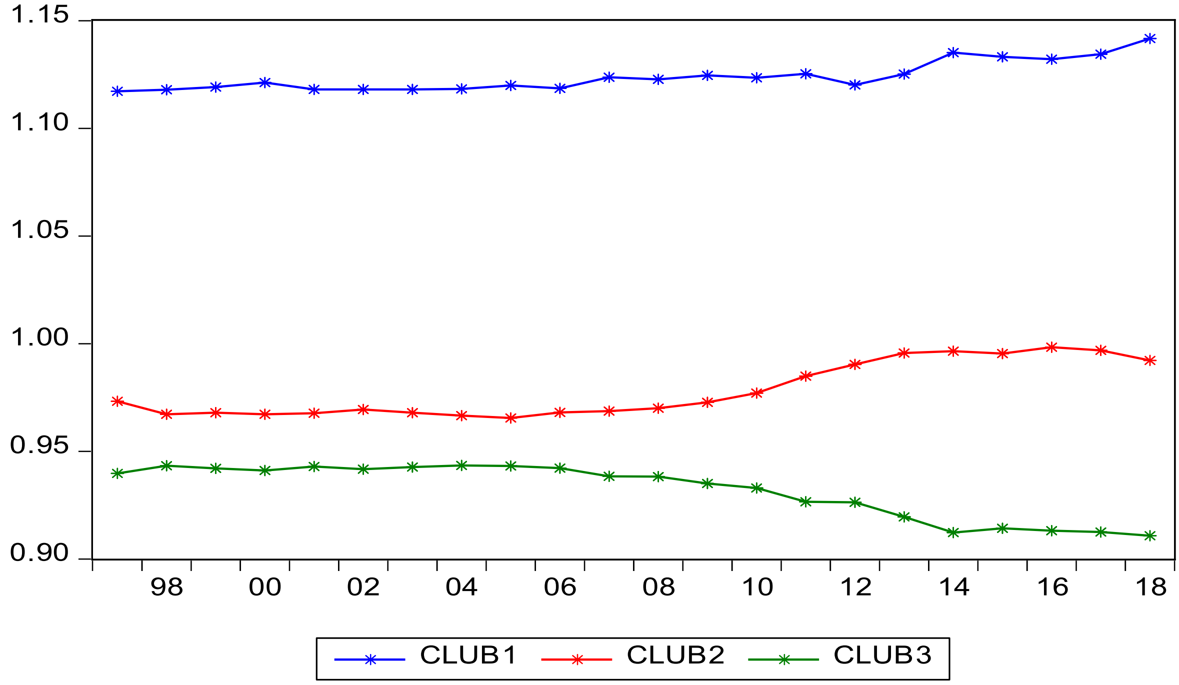


Figure 1 shows the relative transition paths of clubs. We observe that while Club 1 is above the panel average, Clubs 2 and 3 are below the panel mean. Besides, we do not show any convergence tendencies across clubs. After 2006, we observe a clear divergence between Club 2 and 3. Converging to lower states of greenhouse gas emissions of Club 3 indicates an improvement in environmental quality. Figures 2, 3 and 4 show the relative transition paths of countries. Relative transition paths of countries deserve more interpretation. Figure 2 shows the relative transition paths of Canada and the United States. We observe a convergence between these countries. Until 2011, while the level of greenhouse gas emissions of the United States is below that of Canada, since then, Canada's values have been higher than the United States. For both countries, we observe an upward trend. Figure 3 shows the relative transition paths of countries in Club 2. We observe an increase in greenhouse gas emissions in Japan, especially after 2010, which indicates an increasing environmental degradation. Besides, we observe a strong convergence between Japan and Germany, especially after 2008. An increase in the urban population in Japan may be a factor in the increase in greenhouse gas emissions. On the other side, despite an increase in GDP per capita, a rise in the share of renewable energy sources of energy production might contribute to a decrease in greenhouse gas emissions in Germany (Huenteler et al., 2012). Finally, Figure 4 shows the relative transition paths of countries in Club 3. For all countries in Club 3, we observe a decreasing trend, which shows an improvement in environmental quality. Furthermore, we observe a convergence across France, Italy and the United Kingdom.

Figure 2: Relative Transition Paths of Countries in Club 1

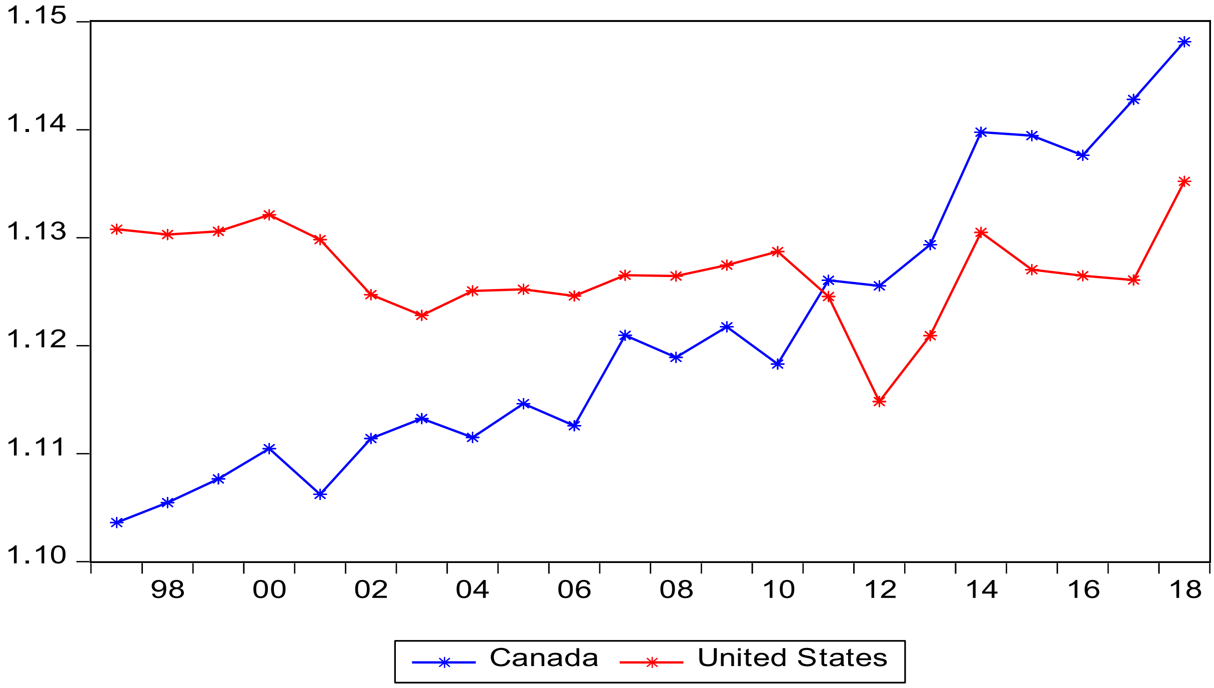


Figure 3: Relative Transition Paths of Countries in Club 2

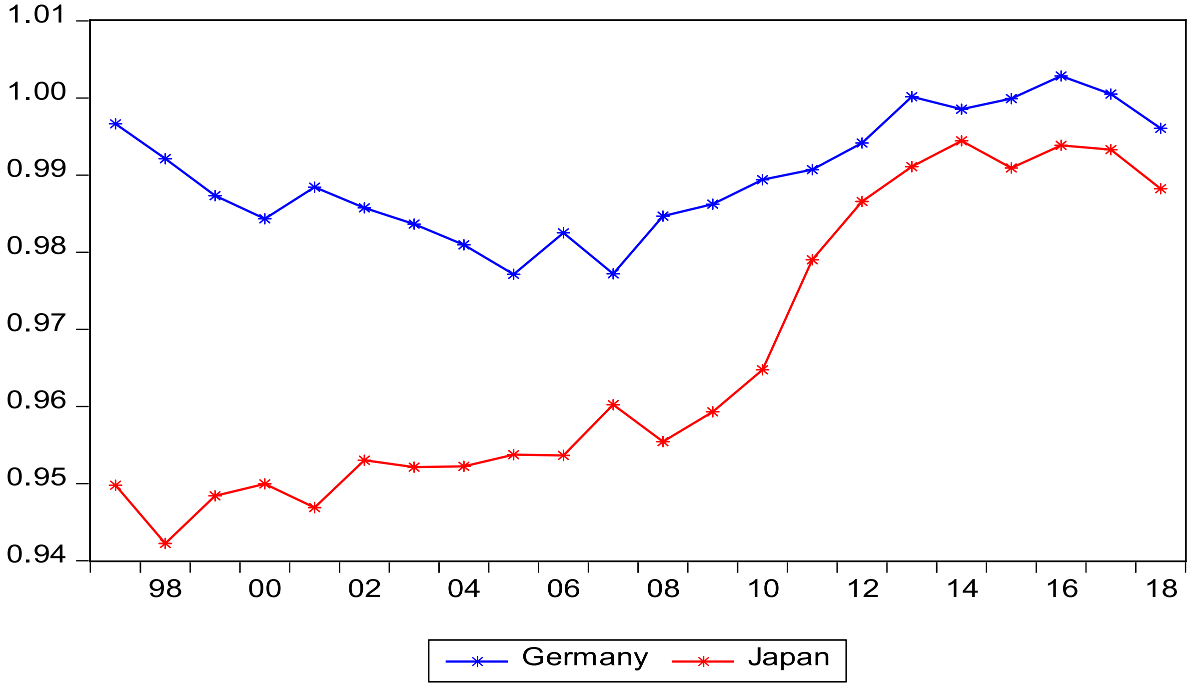
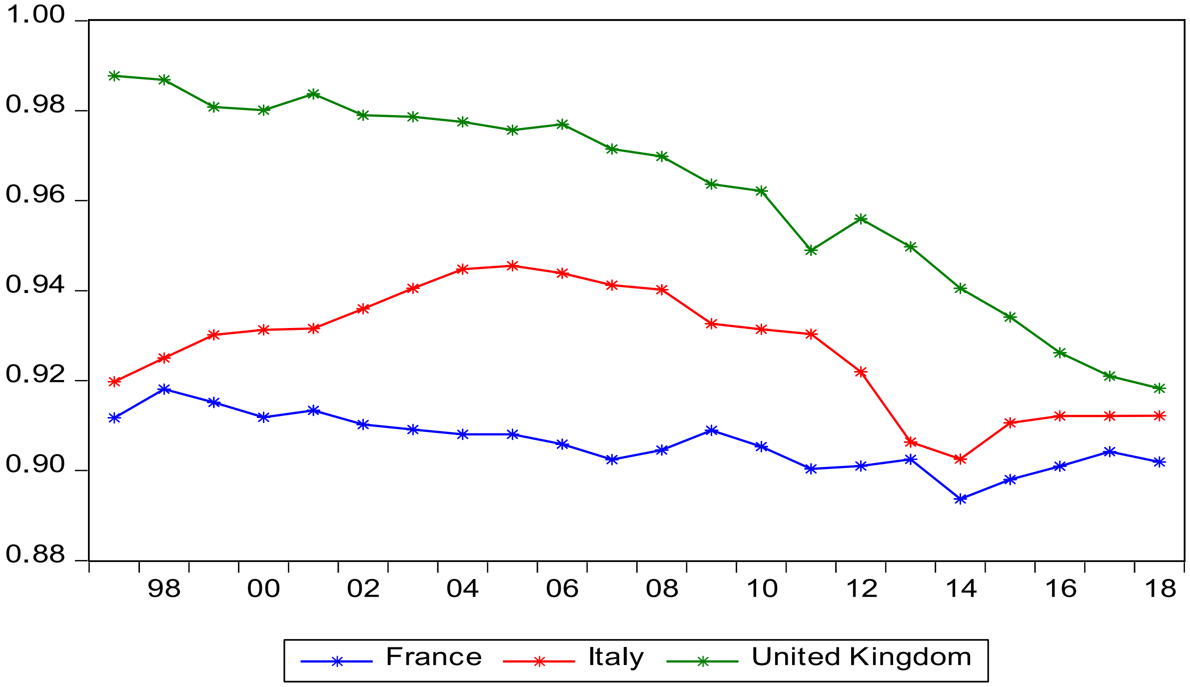


Figure 4: Relative Transition Paths of Countries in Club 3



To authors' best knowledge, there is no study testing convergence in greenhouse gas emissions across G-7 countries using club convergence methodology developed by Phillips & Sul (2007). Therefore, we may compare our results with other studies using different empirical methodologies or environmental indicators. Our empirical findings are consistent with Yavuz & Yılancı (2013) which test the convergence in carbon dioxide emissions across G-7 countries using the threshold autoregressive (TAR) panel unit root test methodology. The findings show that there is conditionally convergence during the decade of the 1960s and after 1990 and diverge between 1970 and 1990. Similarly, Yılancı et al. (2021) conclude that there is absolute convergence in ecological footprint and carbon footprint across G-7 countries using the panel Fourier threshold unit root test. Montasser et al. (2015) test the convergence in greenhouse gas emissions across G-7 countries using the pairwise test method. They conclude that the convergence hypothesis is not valid for G-7 countries.

5. Conclusion

In recent years, numerous studies have studied the environmental convergence hypothesis for different group of countries. Testing the environmental convergence hypothesis may help policy-makers to implement more efficient environmental policies. One can say that such policies could be more efficient in case of convergence in environmental indicators across countries.

Within this motivation, we investigate the convergence in greenhouse gas emissions per capita across G-7 countries over 1997-2018. For this purpose, we apply the log-t test methodology developed by Phillips & Sul (2007). The results show that all countries do not converge to a single equilibrium state. However, the club clustering algorithm determines three convergence clubs, each converging to a different steady-state equilibrium. Club 1 includes Canada and United States, whereas Club 2 includes Germany and Japan. Finally, Club 3 includes France, Italy and United Kingdom. The relative transition paths of clubs show that while Club 1 is well above the panel average, Clubs 2 and 3 are below the panel mean. Furthermore, we do not observe convergence tendencies across clubs. Especially for Club 3, we observe a divergence pattern to a lower steady-state equilibrium, which indicates an effective environmental policy and improvement in environmental quality.

Overall, our results show that G-7 countries differ in terms of environmental degradation. Therefore, the policies to prevent environmental degradation should be country-specific. In other words, instead of implementing common environmental policies, including international agreements, governments also consider implementing national-based policies to prevent environmental degradation in their countries.

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