The relationship between economic growth and carbon emissions in G-7 countries: evidence from time-varying parameters with a long history

Mehmet Akif, Destek and Muhammad, Shahbaz and Ilyas, Okumus and Shawkat, Hammoudeh and Avik, Sinha

Gaziantep University, Gaziantep, Turkey, Beijing Institute of Technology, Beijing, China, Hatay Mustafa Kemal University, Antakya, Hatay, Turkey, Drexel University, Philadelphia, PA, USA, Goa Institute ofManagement, Goa, India

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Abstract: This paper re-investigates the time-varying impacts of economic growth on carbon emissions in the G-7 countries over a long history. In doing so, the historical data spanning the period from the 1800's to 2010 (as constructed) for each country is examined using the time-varying cointegration and bootstrap-rolling window estimation approach. Unlike the previous Environmental Kuznets Curve (EKC) studies, using this methodology gives us avenue to detect more than one, two or more turning points for the economic growth-carbon emissions nexus. The empirical findings show that the nexus between economic growth and carbon emission seems over a long history to be M-shaped for Canada and the UK, N-shaped for France, inverted N-shaped for Germany, and inverted M-shaped (W-shaped) for Italy, Japan and the US. This empirical evidence provides new insights to policy makers to improve environmental quality using economic growth as an economic tool for the long run by observing changes in the environmental impact of this growth from year to year

Keywords: Environmental Kuznets Curve, Chebyshev Time-polynomials, Time-varying Cointegration, G-7 Countries

1. Introduction

The reports on an increase in global warming by 1.5^{o}C that was published by the Intergovernmental Panel on Climate Change (IPCC) point out human activities have caused the earth to warm up by about 1.0^{o}C, compared with the pre-industrial period. The IPCC's last report notes that global warming and climate change have already led to extreme weather conditions, including rises in sea level and melting of ice in the poles. It is further claimed that migration and exile due to climate conditions will increase, the economic cost of climate change will reach astronomical dimensions and the global ecological system will collapse if global warming exceeds 1.5 degrees (IPCC, 2018). CO_2 emissions, which are responsible for approximately 75% of greenhouse gas emissions, have been one of the most significant sources of global warming and climate change (Atasoy, 2017). Although several strategies have been determined in the Kyoto Protocol of the Paris Agreement to reduce CO_2 emissions and many other summits, burning fossil fuels with the aim of achieving high economic growth has increased CO_2 emissions (Churchill, 2018). Therefore, the impact of economic growth on environmental pollution has become one of the most debated issues for environmentalists and economists.

In the extant body of knowledge, connotation between economic activities and ecological damage has been generally reconnoitered by using environmental Kuznets curve (EKC) hypothesis. This gives rise to an inverted U-shaped curve, following the seminal work of Grossman and Krueger (1991). According to this hypothesis, initially augmentation in economic activity will create environmental degradation, but beyond a certain level of income, a rise in economic activity will decrease environmental degradation. This inverted-U shaped relationship commonly is rationalized by positing that at the initial stage, people focus more on economic growth than on environmental pollution because the aim is to reach a better standard of living. After reaching better living practices, citizens prefer to have superior ecological condition than to achieve economic growth. Consequently, economic growth itself is conducive to reaching a better environmental quality. Because of this simple logic, the EKC hypothesis has highly been analyzed for different countries in different time spans by applying various econometric approaches (Ahmad et al. 2017). However, rationality of this hypothesis is still a controversial issue in the literature particularly when the relationship goes over a long time period (Dinda, 2004; Yang et al., 2015; Churchill et al., 2018).

There are some reasons behind the contradictory evidences about actuality of the EKC hypothesis. Majority of the works analyzing this association use a quadratic functional form of the carbon emissions model. However, various studies utilize a cubic or a quartic functional form when investigating the mentioned nexus (Lindmark, 2002; Azomahou et al., 2006). In the reduced functional forms used in previous studies, the empirical models are pre-defined and the model outcomes determine various possible forms of the curve (Yang et al., 2015). Using these forms of the EKC hypothesis model could lead to a limitation in determining the shape of the nexus between growth and environment (Esteve and Tamarit, 2012). This limitation could be one of the possible reasons for the lack of consensus on the nexus in the EKC literature. Consequently, unlike different other studies; current paper utilizes a time-varying model, using the bootstrap estimation to explain the effect of economic growth on CO_2 emissions.

Another possible reason why the EKC hypothesis is still controversial could be due to the lack of studies using exceptionally long time periods. Using the historical data of individual countries offers an advantage in understanding the dynamics of the EKC hypothesis over the cross-section with short history approaches. Although the investigation is conducted solely on the temporal domain, the time spans of the studies are too brief to explain modern high-income countries' industrialization progress which dates from the 19th or even the 18th centuries (Lindmark, 2002). In addition, it has been claimed that using long time series to check the growth-degradation nexus reveals much less stable development paths. Unruh and Moomaw (1998) found that a shock like the OPEC catastrophe of 1973 had instigated the course of greenhouse gasses to pass in the direction of being a new "attractor". This is due to the fact that the dynamic systems may show complex behavioral patterns and the claim that using ordinary analytical methods with short time series is not enough to reflect the nexus between economic activities and carbon emissions. Therefore, marrying long historical time series data with the appropriate methodology is an ideal idea that brings stability and flexibility, which we follow in this paper.

Following these reasons, our study adds to the extant energy economics domain in a three-fold manner: (i) It re-observes the linkage amid economic prosperity and CO_2 discharge for the G-7 countries, using historical data over 1800s-2010. The selection of sample country group is influenced by the contextual evidence that the G-7 countries have experienced the highest growth rates over the last 150 years, and this allows one to better observe the effect of growth on carbon emissions over many years (Churchill et al., 2019). (ii) The bootstrap-rolling window estimation approach is applied, which allows us to determine complex behavior patterns of the EKC hypothesis over an extended spell of time. Assumption of parameter constancy when examining the relationship between long-sample series may lead to erroneous policy recommendations. In such cases, time-varying parameters, recursive estimates or rolling parameters are generally used. The argument of Barnett et al. (2012) that rolling window estimations lead to more consistent results than time-varying and recursive estimates constitutes the rational for the method used in this study. As a matter of fact, the findings from the rolling estimation reveal that the connotation between financial performance and ecological deterioration seems to have an M-shape for Canada and the UK, an N-shape for France, an inverted N-shape for Germany, and an inverted M-shape (W-shape) for Italy, Japan and the US.

(iii) We divide the entire data into two regimes: the before-the-OPEC 1973 shock and the after-the-OPEC 1973 shock in order to examine the pattern of the EKC hypothesis in the G-7 countries since this major oil shock triggered a series of hefty oil price increases. Moreover, the other reason for dividing the sample into two regimes before and after 1973 is because the effects of the 1973 first oil crisis had led to an active search for alternative sources of energy to reduce fossil energy dependencies and to recognize that the most significant impact on pollution in the observed period has come from fossil fuels. As a result of this division, it is observed that the 1970s were the period when the strong harmful impact of growth on carbon emissions began. However, the strong negative impact continued until the 2000s.

The remainder of this paper is outlined by the following sections: section two discusses the existing knowledge, section three provides evidence regarding the data and techniques applied, section four discusses the obtained model outcome, and finally, fifth section presents concluding remarks with policy implications.

2. Literature review

The Environmental Kuznets Curve (EKC) hypothesis has been observed by numerous empirical studies during the last three decades. For instance, Grossman and Krueger (1991) initially demonstrated the affiliation between ecological condition and economic growth by referring to the environmental Kuznets curve. Their study investigated the effects of economic activities on some pollutants (SO_2 and smoke) of having NAFTA. Those authors reported the existence of the EKC hypothesis. Following their study, there have been a number of works testing the hypothesis for different pollutants, explanatory variables and countries or country groups using various econometric approaches. In addition, the models utilized in the EKC estimation are usually quadratic or cubic forms. According to the standard functional form used in the analysis, the growth-ecological deterioration is determined as an inverted U-shape, a U-shape, an N-shape, an inverted N-shape or a monotonically increasing/decreasing function (for additional details, see Shahbaz and Sinha, 2019). Therefore, we classified the EKC literature on the basis of the functional form specifications and the shapes of the relations.

An extensive assessment of EKC studies over 1998-2019 is represented in Table-1. Most of the studies that investigate the EKC hypothesis using the quadratic form and show an inverted U-shaped connotation amid economic prosperity and carbon discharge. The studies include Suri and Chapman (1998) for 33 countries, Dinda et al. (2000) for 33 countries, Stern and Common (2001) for global and OECD countries, Ang (2007) for France, Jalil and Mahmud (2009) for China, Iwata et al. (2010) for France, Nasir and Rehman (2011) and Shahbaz et al. (2012) for Pakistan, Esteve and Tamarit (2012) for Spain, Saboori et al. (2012a) for Malaysia, Saboori and Sulaiman (2013) for Malaysia, Shahbaz et al. (2013a) for Romania, Shahbaz et al. (2013b) for Turkey, Tiwari et al. (2013) for India, Farhani et al. (2013) for MENA countries, Chow and Li (2014) for 132 countries, Cho et al. (2014) for OECD countries, Shahbaz et al. (2014a) for Tunisia, Yavuz (2014) for Turkey, Shahbaz et al. (2014b) for UAE, Farhani et al. (2014a) for MENA countries, Farhani et al. (2014b) for Tunisia, Bölük and Mert (2015) for Turkey, Kasman and Duman (2015) for EU countries, Shahbaz et al. (2015) for Portugal, Balaguer and Cantavella (2016) for Spain, Javid and Sharif (2016) for Pakistan, Rafindadi (2016) for Japan, Al-Mulali et al. (2016) for Kenya, Al-Mulali and Ozturk (2016) for 27 advanced economies, Li et al. (2016) for 28 Chinese provinces, Atasoy (2017) for 50 US states, Ahmad et al. (2017) for Croatia, Solarin et al. (2017) for India and China, Destek et al. (2018) for 15 EU countries, Balaguer and Cantavella (2018) for Australia, Pata (2018) for Turkey, Raza and Shah (2018) for G7 countries, Khan and Ullah (2018) for Pakistan, Destek (2019) for 12 CEE countries, Shahbaz et al. (2019) for the G7 countries, Bulut (2019) for the USA, and Destek and Sarkodie (2019) for the 11 newly industrialized countries.

However, the evidence of U-shaped connotation among economic prosperity and greenhouse gasses is reported by Wang et al. (2011) for 28 Chinese provinces, Saboori et al. (2012b) for Indonesia, Ozcan (2013) for Middle East countries, Begum et al. (2015) for Malaysia, Ozturk and Al-Mulali (2015) for Cambodia, Jebli and Youssef (2015) for Tunisia, Dogan and Turkekul (2016) for the USA. In contrast, Pao et al. (2011) used the quadratic model and found a monotonically decreasing relationship between income and environmental pollution for Russia. Al-Mulali et al. (2015) and Farhani and Ozturk (2015) investigated the EKC hypothesis using the quadratic form and concluded that monotonically increasing movement persists for Vietnam and Tunisia, respectively.

Some previous studies used the cubic models to test the EKC hypothesis. For example, Brajer et al. (2011) used the cubic form of the estimation model to analyze the EKC hypothesis in 139 Chinese cities for the period 1990-2006 and confirmed the validity of hypothesis. Similarly, Fosten et al. (2012) examined the connotation between economic prosperity and CO_2 discharge for the period from 1830 to 2003 in the UK, utilizing a cubic form of the EKC model. Their results based on the OLS showed that there persists an N-shaped nexus between economic prosperity and CO_2 discharge. Akbostancı et al. (2009) also used the cubic form of the EKC model in 58 Turkish provinces for the period from 1992 to 2001. They found an N-shaped connection between the variables. In addition, Denhavi and Haghnejad (2012) utilized the cubic form of the model to assess the EKC hypothesis for 8 OPEC countries over 1971-2008 using the panel FMOLS approach. The study outcome designated that there is a long run N-shaped impact of increasing economic prosperity on pollution.

Yang et al. (2015) investigated the validity of the EKC hypothesis in 67 countries for the period 1971-2010 and their results validated the presence of an M-shaped EKC curve for East Asia and Pacific countries. They also noted an inverted N-shaped relationship amid economic prosperity and carbon discharge for Latin America and Caribbean countries. Following a similar parametric setting, Shahbaz et al. (2017) analyzed the scenario for the USA over 1960-2016 and using both the quadratic and cubic specifications, and their study divulged inverted U-shaped connotation for the quadratic specification, and N-shaped connotation cubic specification. Likewise, Shahbaz et al. (2019) explored the nexus between economic prosperity and ecological deterioration in Vietnam over 1974-2016 by employing both the specifications of the model, like the previous study. The ARDL results indicated that there is an inverted U-shaped relationship for the quadratic form and an N-shaped connotation amid the model parameters. Wang (2019) scrutinized the cogency of this hypothesis for the BRICS nations over 1992-2013, using cubic specification of EKC. GMM outcome showed persistence of an N-shaped connotation between economic prosperity and carbon discharge. Even Gerni et al. (2018) used the quartic model to examine the nexus between GDP and environmental pollution for 59 developed and developing countries. Their empirical analysis revealed the occurrence of inverted M-shaped (W-shaped) connotation between economic prosperity and carbon discharge.

Most of the EKC studies cited so far utilize the quadratic or cubic functional form of the model to capture the possible turning points of the carbon emissions function. Using the quadratic or cubic functional form can lead to a loss of flexibility that may fail to detect the true shape of the relationship between the two variables over time. This limitation of quadratic or cubic functional form has been criticized by many authors in the existing literature. For example, He and Richard (2010) scrutinized the rationality of the EKC hypothesis in Canada over 1948-2004, using a nonlinear parametric modeling method. They found that there is a unilaterally direct connotation between GDP and environmental pollution but the slope of the function changes over time. Ajmi et al. (2015) analyzed the relationship amid power utilization, economic growth and environmental degradation for the G7 countries over 1960-

2010, by means of temporally-fluctuating Granger causality approach. They found substantial temporally-fluctuating causalities from economic prosperity to carbon discharge which are N-shaped for the UK and inverted N-shaped for Italy and Japan. In addition, Shahbaz et al. (2016) examined the relationship between economic prosperity, power utilization, and carbon discharge in the Next 11 nations over 1972-2013 using a temporally-fluctuating causality approach. They found unidirectional causality from economic growth to CO_2 emissions in Turkey and Indonesia. Apergis (2016) also probed the long-run time-varying connotation amid economic prosperity and carbon discharge for 15 countries over 1960-2013. This author pointed out that time independent coefficients might be improper for scrutinizing the cogency of the EKC hypothesis. Shahbaz et al. (2017) verified the cogency of this hypothesis for the G7 nation for approximately two hundred years, employing the nonparametric econometric techniques. The analysis results confirmed the existence of this hypothesis in Canada, France, Germany, Italy, the UK and the US. Sinha et al. (2019) have given a detailed mathematical explanation on this ground.

Similarly, Aslan et al. (2017) investigated the connotation amid GDP and CO_2 discharge in the USA over 1966-2013 utilizing the bootstrap rolling window estimation approach. They study divulged that inverted U-shaped connotation persists amid economic prosperity and ecological deterioration in the US. Taking the similar methodological approach, Ozcan et al. (2018) explored the existence of the EKC hypothesis in Turkey over 1961-2013. The empirical analysis indicated the absence of the EKC hypothesis for Turkey. Aslan et al. (2018) examined the presence of the sectoral EKC hypothesis for the United States over the period 1973-2015 using the rolling window approach. They found a presence of an inverted U-shaped relationship for industrial, electrical and residential carbon emissions. Wang and Li (2019) employed the algorithm-based grey Verhulst model to scrutinize the cogency of this hypothesis in China over 1990-2014 and confirmed its existence. Likewise, Nie et al. (2019) explored the nexus between growth and emissions spanning the period from 1995 to 2014 for Eastern, Western and Central regions of China using the panel threshold regression model and concluded that the inverted U-shaped EKC model is held in Central and Western regions of China. Aydin et al. (2019) employed the panel smooth transition regression (PSTR) to examine the existence of the EKC hypothesis in 26 European Union countries over 1990-2013 and study outcomes refute the persistence of this hypothesis.

<Place for Table 1>

Based on the above discussion, we may note that empirical works analyzing existence of the EKC hypothesis is rising. This reveals that despite some exceptions, most of quantitative works depend on well-defined EKC schemas with little attention paid to model robustness. Therefore, this situation can lead to a functional misspecification problem which causes significantly different conclusions. In addition, most of the empirical studies assumed that the utilized variables in the models have stable properties and reflect the whole sample. In the literature, it seems that there are contradictory findings based on application of the different empirical approaches, as well as functional specifications. Furthermore, it is seen that the studies which assess the rationality of the EKC hypothesis with time-varying tests instead of pre-defined EKC models, the cointegrating connotation between economic prosperity and CO_2 discharge is generally examined with normal polynomial trends instead of Chebyshev polynomials. However, Chebyshev polynomials have the advantage of being an orthogonal basis (while normal polynomials are not) and computation with orthogonal bases also tends to be more stable. Therefore, further investigation of the growth-emissions nexus using recent empirical approaches such as the Chebychev time-polynomials seems to be worthy of more examination.

3. Data and Methodology

3.1 The Data

The data used in this paper is annually and different for each country due to a diverse data availability. Therefore, the relationship between real GDP per capita and CO_2 emissions per capita is investigated for period 1870-2010 for Canada and Japan, the period 1820-2010 for France, the period 1850-2010 for Germany, the period 1860-2010 for Italy and the period 1800-2010 for the United Kingdom and the United States. The data set is constructed until 2010 which determines the availability of this long historical data. The data on the per capita GDP is obtained from the Maddison Project (2015) and measured in a common currency, which is the GK dollars. The GK dollars are the international Geary Khamis dollars which are used with the intent of placing the economic activity for each nation on an equal footing based on the purchasing power parity. The data on the per capita CO_2 emissions are retrieved from the Carbon Dioxide Information Analysis Center (CDIAC) and measured in metric tons.

3.2 The Time-varying Cointegration Approach

In order to investigate the time-varying effects of economic growth on carbon emissions, we should test whether the validity of cointegration between variables is time-varying. Therefore, we use the error-correction based time-varying cointegration test developed by Bierens and Martins (2010). The main error-correction form of a VAR model is proposed by Johansen (1991, 1995) as follows:

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \Pi X_{t-1} - \gamma_0 - \gamma_1 t + \varepsilon_t, \quad \varepsilon_t \sim N_k(0, \Omega) \tag{1}$$

where X_t indicates the $k*1$ matrix of model parameters for period $t = 1,2, \dots, T.$ Moreover, Ω and Φ_j are $k*k$ conditions for $j = 1, 2, \dots, p-1,$ whereas (γ_0, γ_1) refer to the $k*1$ matrices of the intercepts and drift constants, correspondingly, of the vector error-correction model.

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha \beta_t' X_{t-1} + \gamma_0 + \varepsilon_t, \quad t = 1, \dots, T \tag{2}$$

where α refers to the fixed $k*r$ matrix and β_t indicates the temporally-changing $k*r$ matrix of rank r. During testing procedure, the null of the temporally-independent cointegration $\Pi_t' = \Pi' = \alpha\beta_t'$ is validated counter to the alternative hypothesis of the temporally-changing cointegration $\Pi_t' = \alpha\beta_t'$. Based on the assumptions of the average levelness and orthonormality settings, Bierens and Martins (2010) contend that coefficients of β_t might be appraised by restricted total of Chebyshev periodic polynomials $P_{i,T}(t)$ of diminishing levelness of mixed m as follows:

$$\beta_t = \beta_m(t/T) = \sum_{i=0}^{m} \xi_{i,T} P_{i,T}(t), \quad t = 1, \dots, T \tag{3}$$

are unknown $k{*}r$ matrices where $1 \le m < T-1$ and $\xi_{i,T} = \frac{1}{T}\sum_{t=1}^{T} \beta_T P_{i,T}(t)$ for $i = 0, \dots, T-1$. In addition, the Chebyshev periodic polynomials are delineated as:

$$P_{0,T}(t) = 1, P_{i,T}(t) = \sqrt{2}\cos\left(\frac{i\pi(t-0.5)}{T}\right) \tag{4}$$

where $t = 1, 2, \dots, T$ and $i = 1, 2, 3, \dots$Further, the normal distribution of Chebyshev periodic polynomials are orthogonal. Thus, for all pairs of numerals (i, j), subsequent hypothesis is constructed as a time-invariant cointegration: $H_0\colon \xi_{i,T} = O_{k*r}$, for $i = 1, \dots, m$, and $\xi_i = O_{k*r}$ for $i > m$. Temporally-changing cointegration: $H_1\colon \lim_{T\to\infty} \neq O_{k*r}$ for some $i = 1, \dots, m$, and $\xi_i = O_{k*r}$ for $i > m$.

In this case, if Eq. (3) is substituted in Eq. (2), the following model is obtained as:

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha\xi' X_{t-1}^{(m)} + \gamma_0 + \varepsilon_t \tag{5}$$

where $\xi' = \xi_0', \xi_1', \dots, \xi_m'$indicates a *r*(m+1)k* matrix of rank r and $X_{t-1}^{(m)}$ is constructed as follows:

$$X_{t-1}^{(m)} = (X_{t-1}', P_{1,T}(t)X_{t-1}', P_{2,T}(t)X_{t-1}', \dots, P_{m,T}(t)X_{t-1}')'. \tag{6}$$

In Eq. (5), null hypothesis of temporally-independent cointegration turns out to be $\xi' = (\beta', O_{r,k,m})$ and $\xi' X_{t-1}^{(m)} = \beta' X_{t-1}^{(m)}$ with $X_{t-1}^{(0)} = X_{t-1}$ and might be verified with a likelihood ratio test as follows:

$$LR_T^{tvc} = -2\left[\widehat{l_T}(r,0) - \widehat{l_T}(r,m)\right] \tag{7}$$

Eq. (7) distinguishes two scenarios: First, in the temporally-independent scenario, $m = 0$, however in temporally-changing scenario, $m > 0$. Furthermore, in the first scenario $\widehat{l_T}(r,0)$

is the log-likelihood of the error correction model of p-th order, so that $X_{t-1}^{(m)} = X_{t-1}$. In the second scenario, $\widehat{l_T}(r, m)$ is also the log-likelihood of the error correction model of p-th order. In these two scenarios, r is cointegration rank, and LR_T^{tvc} is asymptotically dispersed following χ^2 with d.o.f. of $r*m*k$ (Bampinas and Panagiotidis, 2015).

3.3 The Bootstrap Rolling Window Approach

In the case of the presence of the time-varying cointegration between the variables, it is crucial to determine the most suitable method for having reliable findings. There are three methodologies frequently used in econometric applications to estimate in presence of structural breaks or when parameters are not stable: the recursive approximation, time-varying parameters (TVP) and the rolling estimation. The recursive and TVP approximations are analogous because minor end of the likelihood window is retained and advance towards a groove window, while moving in the same way. With the propagation of the window, additional information is collected, and by the last data point, they are in the similar lines with the model estimate. Given the parameters are perpetual, recursive and TVP measures congregate to the perpetual parameters, keeping with rise in sample volume. This means that the successive estimation errors are reduced for the estimation of the parameters due to the increase in the information in the predictions (Lotz et al., 2014).

However, for more than one structural break, this method might be ineffective, as the effect of the preceding break on the latter might be inclusive. For compound breaks, it is desirable to provide additional preference to the current data points and to reject the data, which has touched a specific period and has crossed the termination date. A superior technique to accommodate parameter inconsistency is to ground the approximation merely on the end section of the data. It initiates the rolling approximation employed in this article. Choice of rolling prediction is grounded on superior accommodating parameter-varying proficiency. Furthermore, in application to the time-varying betas, Barnett et al. (2012)

conclude that the rolling window approximation marginally outclasses further techniques, such as time-varying estimations and recursive estimations.

Based on the above reasons, we utilize the bootstrap rolling window approximation technique established by Balcilar et al. (2010) to examine time-varying parameters of real GDP on CO_2 emissions. This methodology is mainly based on the bivariate VAR(p) process[1] as follows:

$$\begin{bmatrix} y_{CO,t} \\ y_{GDP,t} \end{bmatrix} = \begin{bmatrix} \varphi_{CO} \\ \varphi_{GDP} \end{bmatrix} + \begin{bmatrix} \varphi_{CO,CO}(L) & \varphi_{CO,GDP}(L) \\ \varphi_{GDP,CO}(L) & \varphi_{GDP,GDP}(L) \end{bmatrix} \begin{bmatrix} y_{CO,t} \\ y_{GDP,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{CO,t} \\ \varepsilon_{GDP,t} \end{bmatrix} \tag{8}$$

where $y_{CO,t}$ and $y_{GDP,t}$ indicate the natural logarithms of CO_2 emissions per capita and real GDP per capita, respectively. In addition, $\varepsilon_{CO,t}$ and $\varepsilon_{GDP,t}$ are stochastic noise progressions with mean at zero, and with non-singular covariance matrix Σ and $\varphi_{ij}(L) = \sum_{k-1}^{p} \varphi_{ij,k} L^k$, $i,j = CO, GDP$ where the lag operator (L) is computed as $L^k x_t = x_{t-k}$ (Balcilar et al. 2010). Based on the above explanations, the effect of real GDP per capita on CO_2 emissions per capita is computed as follows:

$$B^{-1} \sum_{k-1}^{P} \hat{\varphi}^{*}_{CO,GDP,k} \tag{9}$$

where B^{-1} represents the number of bootstrap repetitions and $\hat{\varphi}^{*}_{CO,GDP,k}$ is obtained from the bootstrap estimation of the VAR model in Eq. (1). Moreover, the 95-percent level confidence interval is computed as determining the upper and lower bounds with the 97.5 and 2.5 quantiles of $\hat{\varphi}^{*}_{CO,GDP,k}$, respectively (Nyakabawo et al., 2015).

4. Model Outcome and Arguments

4.1. Outcome of Unit Root Test

[1] The bootstrap procedure gathers rational critical or p-values notwithstanding the integration–cointegration nature of the model parameters, as they are calculated out of the quantitative distribution extracted against the representative information. Horowitz (1994), Mantalos and Shukur (1998), and Mantalos (2000), amidst several others, demonstrate the efficacy of this procedure. Grounded on Monte Carlo simulations, Mantalos and Shukur and Mantalos demonstrated that the outcomes are unswerving regardless the volume of sample, nature of stationarity, and error-correction procedures (homoscedastic or autoregressive conditional heteroskedasticity). Based on these arguments, all rolling experiments are carried out by means of the procedure devised by Balcilar et al. (2010).

At the initial phase of our empirical examination, stationarity properties of real GDP per capita and CO_2 emissions per capita in the context of the G7 nations by employing the Ng and Perron (2001) unit root test are investigated. Empirical outcome of the test are exemplified in Table-2. In accordance with the outcome, null hypothesis of non-stationarity is accepted at the level for real GDP per capita and CO_2 emissions per capita. Nevertheless, after the first derivative the null hypothesis can be rejected, and all series have turned out to be static for all countries. This shows that real GDP per capita and CO_2 emissions per capita have a unique level of integration for the G7 countries, i.e. I(1).

<Place for Table 2>

4.2. The Results of Time-Varying Cointegration Test

Now, we focus on the empirical examination of the long-term connotation between economic prosperity and carbon discharge to determine the cogency of EKC hypothesis. In particular, we are concerned with the question of whether the parameters indicating the consequences of economic prosperity on ecological deterioration have changed over time, moving beyond the classical quadratic assumption of the EKC hypothesis. Before obtaining these parameters, the time-varying cointegration test is used to determine whether the validity of the long-run relationship between these variables is time-invariant or time-variant. The test outcome are demonstrated in Table-3.

<Place for Table 3>

Outcome demonstrated in Table-3 divulge that null hypothesis of temporally-independent cointegration is strongly overruled for the G-7 countries with the Chebyshev polynomials ranging from 1 to 4. This empirical finding supports the main view of long-run connotation amid economic prosperity and carbon discharge is time-variant and the consequences of economic prosperity on carbon discharge should be observed with the time-varying coefficients. This situation can be explained with the theorem developed by Swamy and Mehta (1975) that any non-linear mathematical expression could be fully characterized by an empirical schema that is linear in the variables, nonetheless having temporally-changing coefficients. Similarly, in the EKC hypothesis based on a non-linear assumption, income elasticity of pollution is not governed solely by the progression of GDP and theoretically is influenced by additional model parameters. Therefore, the time-varying income elasticity is more consistent in terms of a more accurate observation of the CO_2 emissions-income relationship (Mikayilov, 2018).

4.3. The Results of Rolling Window Estimation

Based on the finding that connotation amid prosperity and pollution is temporally-changing, we examine the time-varying parameters of real GDP on carbon emissions with the rolling window estimation approach. In addition, following the argument of Sheldon (2017) that using a high-order polynomial may lead to more realistic results for income-emissions nexus, we also utilize the polynomial trends of the obtained parameters to detect the possible turning points. Before this analysis, we examine the optimal lag length for individual rolling VAR model by means of the Akaike Information Criteria (AIC) with maximum 10 lags. The optimal lag orders of the VAR model which minimizes the statistics are determined as 3, 6, 2, 9, 3, 8 and 6 for Canada, France, Germany, Italy, Japan, United Kingdom and United States, respectively.

In the rolling window procedure, another problematic issue is choosing of window dimension and rolling window estimation numbers. Despite the fact that the larger window size leads to more precise estimates, the obtained parameters may not be representative if the heterogeneity is valid. However, reducing the window size to reduce the heterogeneity may increase the variance of each estimate. Pesaran and Timmermann (2005) searched the window size under structural changes and showed that the bias in the autoregressive parameters is lessened with a window size of around 10-20. Therefore, to examine the time-varying parameters for the consequence of real income on carbon discharge, we use constant window dimension of 15 years following the Monte-Carlo simulation outcome of Pesaran and Timmermann (2005). Also, polynomial trend for the coefficient of real income on CO_2 emissions is employed, in order to detect the possible turning points. The results of rolling window estimation approach are reported in Figure-1.

4.3.1. Rolling Window Estimation Results for Full Sample

As a shown in Figure-1, for Canada, the influence of real income on carbon discharge is positive and slightly increasing over 1885-1913. After this period, the estimated parameter of real income has become negative in almost all years covering the period 1913-2008. After 2008, the parameter has become positive again. In the case of France, the parameter of real income is positive and generally increases for the period from 1835 to 1955. The negative effect of real income on CO_2 emissions emerges from 1956 until 2008 and has become positive after 2008. In the case of Germany, it seems the effect of real income is positive between 1865 and 1905, while the negative effect that started from 1906 continues until 1944. After 1944, the positive parameter of real income on carbon emissions prominently increases and this effect is positive for the 1944-1961 period. It is observed that the negative effect which started in 1962 appears to fluctuate until 2010.

Looking at the individual results for Italy, the consequence of real income on CO_2 discharge is generally direct over 1875-1980. However, the negative effect has been valid until 2007. In Japan, the positive consequence of real income on CO_2 discharge can be seen for the period 1885-1945, and also the positive effect is prominently increasing for the period 1945-1957. However, the negative effect started from 1957 and continued to 2001. After 2001, it becomes positive again. In the case of the United Kingdom, the effect fluctuates in the period 1815-2010. In the United States, the effect of real income is positive for 1815-1923 period. For 1923-1955 periods, the effect seems fluctuating. After this period, it becomes negative until 2007.

Overall, the positive effect of real income on CO_2 discharge is valid in case of all nations over the 18th and early 19^{th} century as a reflection of industrial revolution. On the other hand, we have identified some periods in which the positive effect has increased excessively for France, Italy and the United States, and these periods can’t be explained only with the economic development levels of those countries. For instance, the first period in which the parameters increased excessively were 1905-1916 for France, 1913-1918 for Italy, 1910-1922 for the United Kingdom and 1911-1921 for the United States, respectively. When the periods in which the parameters increased for the second time-period and increased more than the first one is examined, it can be seen that these periods are 1940-1949 for France, 1940-1946 for Germany, 1943-1954 for Japan, 1944-1960 for the United Kingdom and 1943-1955 for the United States, respectively. All these periods point to the first and second world wars in which energy is consumed extensively. It is well known in history that WWI, for example, was a war that was fought between men and machines and the latter was powered by oil.

After the above positive effect, it is seen that for almost all countries, the harmful effect of economic growth on pollution started for the period 1956-1980. This is the period when the tendency toward alternative energy sources started for various reasons. For instance, the 1956-1960 sub-period points to the Suez crisis. Egyptian policymakers detained governing power of the Suez Canal from the English and French corporations, and this nationalization had significant concerns for the United States’ dealings with both Middle Eastern nations and European associates. This crisis also endangered to reduce Europe’s oil supply and the threat may also be the reason for the observed negative influence of economic prosperity on carbon discharge, as it directs the G-7 countries toward renewable energy investments in order to reduce their oil dependencies.

The second period in which the negative effect began to intensify was the 1970-1980 period. The year 1970 is a milestone in the U.S. since Congress passed the Clean Air Act Amendments which led to the formation of the air quality standards for this nation. It is possible to explain the negative effect that began in 1970s with the utilization of alternative power sources owing to the advent of energy crises. Furthermore, it is observed that the impact of economic prosperity on ecological deterioration has started again in 2007 for most countries. This negative picture indicates that the economic concerns of countries after the 2007 global financial crisis came at the expense of environmental concerns.

<Place for Figure 1>

When the polynomial trend of the parameters as shown in Figure-1 is evaluated, it can be seen that there is an M-shaped relationship between real income and CO_2 emissions in Canada and the United Kingdom. This finding is consistent with the results of Yang et al. (2015) who argue that an M-shaped curve between economic growth and environmental pollution consists of two stages. This argument for those stages might be elucidated as per the following: in the initial period, economic development level is not high, and at this stage carbon dioxide emissions increase to a certain extent and then decreases. In the second stage, carbon dioxide emissions along with increases in economic growth reach the peak for the second time and then start to decrease again. In addition, we found the evidence of an N-shaped relationship for France and an inverted N-shaped relationship for Germany is valid. Sinha et al. (2017) also found evidence of N-shaped and inverted N-shaped models and argued that the N-shaped model can be explained by the scale effect and the long-term effects of energy efficiency. Namely, once economies have succeeded in reducing pollution rates and ensured the emergence of environmental technical aging, a possible return to increased emissions may occur.

However, an inverted N-shaped configuration exhibits that it might not be indispensable for any country to experience a low magnitude of ecological deterioration, after it has dropped to a threshold. It might be probable for the ecological deterioration to start escalating for the subsequent time due to changes in the socio-economic scenario. Though, in the later levels of economic growth, influence of technology may diminish the ecological deterioratrion. Surprisingly, it seems there is an inverted M-shaped relationship (or a W-shape) between real income and emissions for Italy, Japan and the United States. An inverted M-shaped model is also observed by Gerni et al. (2018) and this finding is associated with economic and political preferences of countries for foreign direct investment as follows: Countries are notable to attract foreign direct investment that increases pollution at the initial stages of economic development, but as the level of development, the level of pollution increases as it becomes a suitable country for foreign capital investment. The country, which gained the status of a developed country, tends to invest in developing countries in pollution-enhancing industries. In the final stages of the development, they again show their willingness to attract large amounts of net foreign direct capital.

4.3.2. Rolling Window Estimation Results for before and after 1973 OPEC Oil Shock

We also investigate the time-varying effect of economic growth on environmental pollution for the pre-1973 and post-1973 oil crisis period to examine the existence of an inverted U-shaped EKC hypothesis for both two sub-periods. In doing so, we utilize the bootstrap rolling window estimation technique and present the findings in Figure-2. In the case of Canada, we found that an inverted U-shaped EKC hypothesis does not exist before and after the OPEC oil shock. In fact, it is discovered that there persists a U-shaped relationship amid economic prosperity and ecological deterioration after the 1973 oil crisis for Canada. In the case of

France, the inverted U-shaped EKC hypothesis is confirmed for the pre-1973 period. However, after the oil crisis, there is an N-shaped relationship between real income and carbon discharge in France. In the case of Germany, the U-shaped curve exists for the pre-1973 period, while the inverted N-shaped relationship is valid for the post-1973 period.

<Place for Figure 2>

For Italy, the inverted-U shaped EKC hypothesis is confirmed for the pre-1973 period. Nonetheless, the connotation between economic prosperity and carbon discharge has turned to the U-shaped curve after the 1973 OPEC oil crisis. In the case of Japan, while an inverted N-shaped curve exists before the oil crisis, there is an N-shaped curve after oil crisis. In the UK, we found that N-shaped curve persists for pre-1973 period, and after oil crisis, the U-shaped curve is validated. Similarly to the France and Italy, an inverted U-shaped EKC hypothesis is supported in the US for the pre-1973 period. After the OPEC oil crisis, it seems the U-shaped relationship exists.

To sum up, after the 1973 oil crisis, it is observed that the effect of economic growth on environmental pollution has changed from positive to negative (for Canada, Germany, Italy, the UK and the US) or the negative effect has decreased (for France and Japan). In addition, although the impact had increased until the 2000s for France and Japan, it was never positive. This finding indicates that fossil energy consumption has been reduced until the 2000s. However, it is not possible to mention the cogency of the EKC hypothesis after 1973. Because, for almost all countries (excluding Germany), the environmental pollution-increasing impact of economic growth has reappeared in the 2000s. The main reason for this situation is that the renewable energy tendency, which accelerated after the oil crisis, slowed down due to the economic crises experienced in the 2000s. After those crisis experiences, the countries decided to place the environmental quality in the second place and to continue the production structure based on the existing fossil energy as rapid solutions that are vital to the economy. The evidence of this tendency is that the G-7 countries have increased the segment of clean energy consumption[2] in aggregate energy consumption from 4.71% to 16.73% for the 1973-2000. However, for the period 2001-2010, this ratio has changed from 16.75% to 16.86% (WDI, 2018).

5. Concluding Remarks and Policy Directions

This study reinvestigates the economic prosperity-ecological deterioration connotation for the G-7 countries spanning the period from 1800's to 2010 as constructed in this historically long database. In doing so, and differently from previous studies, the time-varying parameters of real GDP on carbon dioxide emissions is computed and the objective is to examine the polynomial trend of the computed parameters instead of using the quadratic or cubic EKC form as commonly used in the existing literature. In addition, the study aims to split the impact of real GDP on carbon emissions for the periods before and after the 1973 OPEC oil crisis.

The empirical findings show that there persists an M-shaped curvilinear connotation between real income and CO_2 emissions in Canada and the United Kingdom. This connotation can be explained with the argument that the nexus consists of two junctures. During first juncture, the economic development level is not high and at this stage the carbon dioxide emissions increase to a certain extent and then decreases. In the second juncture, carbon dioxide emissions rising with increases in economic growth reach the peak for the second time and then start to decrease again. In addition, we found valid evidence of an N-shaped relationship in France and an inverted N-shaped relationship for Germany. The N-shaped model can be explained by the scale effect and the abiding consequences of energy efficiency. Namely, once an economy succeeds in reducing pollution emissions and the ensured environmental technical aging emerges, a possible return to increased emissions may

[2] The reason for using the clean power utilization indicator is that this energy never germinates carbon dioxide when produced. It encapsulates hydropower, nuclear, geothermal, and solar power, among others.

occur. However, an inverted N-shaped outline reveals that it might not be necessary for an economy to sustain low ecological deterioration subsequent to it has dropped to a threshold level. Due to transformations in socio-economic setting, it may be possible for ecological deterioration to instigate rising again. Nevertheless, in the later junctures of economic growth, the technical impact may diminish the level of ecological deterioration.

Further, we conclude that there persists an inverted M-shaped relationship (i.e., a W-shape) between real income and emissions for Italy, Japan and the United States. In previous studies, an inverted M-shaped model is associated with the economic and political preferences and ability of countries to attract foreign direct investment. Based on this argument, countries can't attract foreign direct investment in the early stages of economic development, but as the level of development increases, the level of pollution increases as the country becomes suitable for foreign capital investment. This is the reason for the first U-shaped curve between economic prosperity and ecological deterioration. Then, the countries that gained the developed status tend to invest in developing countries in sectors that increase pollution. In the final stages of development, they have again demonstrated their willingness to attract large amounts of net foreign direct investment. Thus, this complements the second U-shaped curve of economic growth on environmental pollution.

Moreover, we scrutinize the impact of economic prosperity on ecological deterioration for both the pre-1973 and post-1973 sub-periods to detect the possible validity of the EKC hypothesis in these sub-periods. Based on this investigation, we found that an inverted U-shaped is confirmed only for the pre-1973 period in France, Italy and the US. Further, the results reveal that the environmental pollution-reducing effect of economic growth is rational in all countries from 1973 to 2000s. However, carbon emissions-increasing effect of economic growth reappears in almost all countries, especially after 2007. It is possible to interpret this finding by positing that most of the developed countries have prioritized economic growth over preventing increasing environmental degradation after the 2008 global financial crisis.

In regard with policy implications, environmental policies should be implemented with the reality that environmental pollution-increasing impact of economic activities has risen again in the 2000s in the G-7 countries, excluding Germany. Undoubtedly, the re-orientation of the G-7 countries to fossil energy sources has played a key role in driving the emergence of this negative situation. However, the fact that countries pay more attention to economic concerns than dealing with environmental issues as a result of the financial crises they experienced in the 2000s, will further increase both economic and environmental damage in the future, and thus has also negative effects on economic activities. Higher health expenditures due to illness, labour productivity losses due to the absence from work for illness, and agricultural yield losses are some of the possible negative impacts of increasing environmental pollution on economic activities.

Based on these reasons, the policy makers of the G-7 countries need to turn to an environmentally sensitive growth strategies rather than short-term solutions that boost short term economic growth. In this direction, some policies should be implemented to increase the share of renewable energy which has an emission-reducing effect in the total energy portfolio as follows: i) Deterrent decisions should be made for the implementation of decisions taken at the political summits between the G-7 countries in order to take environmental measures. ii) Domestic and foreign investors should be encouraged to take an active role in financing research projects that target the development of clean energy technologies. iii) Technological knowledge that reduces the cost of clean energy should be shared with other countries.

Finally, in future studies that investigate the relationship between economic growth and pollution, different complex relations should be taken into consideration because the impact of economic development on pollution also depends on other factors such as economic and political preferences of governments, increased energy consumption during wars, oil crises, etc. In addition, we find that in examining the economic growth-environment nexus, the standard quadratic or cubic form should not be adhered to and that each individual country needs different modelling. These considerations should be considered in future empirical studies.

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