# Environmental Quality Effects of Income, Energy Prices and Trade: The Role of Renewable Energy Consumption in G-7 Countries

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## Abstract

Renewable energy plays a vital role in achieving environmental sustainability, however, the mitigating effect varies across countries depending on the share of renewables in the energy mix. Herein, we analyze the effect of renewable energy consumption, energy prices, and trade on

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emissions in G-7 countries. The results demonstrate that renewable energy and energy prices exert negative pressure on $CO_2$ emissions while trade volume exerts a robust positive pressure on $CO_2$ emissions. The country-specific estimation results provide evidence of a negative effect of energy prices on $CO_2$ emissions. Whereas the environmental Kuznets curve hypothesis is validated at the panel and country-specific levels, the effect of renewable energy consumption and trade, are disparate across countries. The panel Granger causality shows a mono-directional causality flowing from energy prices, GDP, the quadratic term of GDP and trade to $CO_2$ emissions. Renewable energy consumption, however, has no causal relationship with $CO_2$ emissions but indirectly affects $CO_2$ emissions through its direct effect on energy prices. Joint action on trade, energy prices, and country-specific renewable energy policies have implications for environmental sustainability and the attainment of the Sustainable Development Goals (SDGs).

**Keywords**: Renewable energy consumption; energy prices; EKC hypothesis; G7 countries

**JEL Codes**: C33; 057; Q42; Q54

## 1. Introduction

The perspectives of policymakers on global energy-environment dynamics could be well-posited on two main paradigm shifts. The first perception is based on the argument that more implementation of energy diversification of the downstream sector can curb the incessant oil price fluctuations. From another perspective, these conjectures by most environmentalists have consistently been hinged on the need for a global drive towards a cleaner environment and sustainable economic development. Hence, mirroring from the environmental context and especially the conventional Environmental Kuznets Curve (EKC) hypothesis, the role of global energy prices dynamics amidst the increasing use of low-carbon energy sources and energy technologies is worth further scientific examination. The dynamics in global energy prices are observed to cut across the myriad of energy use which includes unleaded premium; oil for industry, households and motor vehicles; natural gas for industry and households; steam coal for industry; and electricity for commercial and residential purposes (International Energy Agency, IEA, 2019). For instance, the IEA reveals that the average price of gasoline in 2018 increased by 14% from the previous year (International Energy Agency, IEA 2019b). The IEA further observes that the European consumers paid the highest gasoline price, thus, suggesting a reflection of the continent's high taxes on fuels as a measure to achieving the low carbon energy targets and Sustainable Development Goals (SDGs) target.

The use of renewable energy and clean energy technologies is one of the prominent mechanisms towards breaking the long-standing link between fuel pollution, carbon emissions ($CO_2$) and economic growth. This is because energy utilization is arguably linked with economic growth, thus indicating that energy consumption is responsible for determining the environmental quality (Rafindadi, 2016; Rafindadi & Usman, 2019; Usman, Iorember & Olanipekun, 2019a).

Consequently, in achieving global environmental sustainability, the United Nations Framework Convention on Climate Change (UNFCC)[2], and a growing number of states among other stakeholders have consistently urged for more commitment to the comprehensive 2015 Paris Agreement[3]. For instance, the share of renewables in total energy consumption is reported to

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[2] "UNFCC is the section of the United Nations organization that is saddled with mitigating global climate change. Further information on UNFCCC is available at https://unfccc.int/."

[3] "The 2015 Paris Agreement by the UNFCC. More details relating to the 2015 Paris Agreement are available at: https://unfccc.int/process/conferences/pastconferences/ paris-climate-change-conference-november-2015/ Paris-agreement."

increase in a five-year period to attain a 12.4% growth by 2023 (International Energy Agency, IEA (2019c). With about 30% of power demand being met by 2023 through renewables, 70% of global growth in electricity generation from renewable energy through solar photovoltaic (PV), wind, hydropower and bioenergy, renewables are expected to be the fastest-growing energy technology in the electricity sector by 2023 (International Energy Agency, IEA (2019c). However, the current global outlook suggests that energy generation from renewables is inadequate to meet the global demand — prominently from the heating, cooling, and transportation sectors (REN21, 2019). Implying that the heavy reliance on fossil fuels, which are mostly subsidized in many countries is persistent amidst the high cost of renewable energy generation and the use of energy technologies (Destek & Sarkodie, 2020).

Considering the role of the world-leading economies, such as the G-7 countries (Canada, France, Germany, Italy, the UK, the US, and Japan) in influencing the dynamics in energy prices and global environmental challenges through policy directions, this study examines the EKC hypothesis in the presence of renewable energy consumption, energy prices and trade volume in G-7 countries. While previous studies (Alola & Alola, 2018; Alola, Alola & Saint Akadiri, 2019; Alola, Bekun & Sarkodie, 2019; Alola et a., 2019; Bekun, Alola & Sarkodie, 2019; Saint Akadiri et al., 2019) have considered the role of renewable energy consumption in mitigating environmental degradation as well as examining the link between energy prices and environmental degradation (Al-Mulali & Ozturk, 2016; Balaguer & Cantavella, 2016; Yilanci & Ozgur, 2019), the current study contributes to the literature in several ways: First, the study jointly investigates the role of energy prices, renewables and trade within the EKC framework in G-7 countries. Second, the study considers the nexus outlined in both panel and country-specific framework in order to unravel joint and country-specific effect of energy prices, renewables and trade on environmental quality. The findings of this paper will reveal whether these economies differ from other economies, particularly the developing and emerging economies regarding the role of renewable energy consumption, energy prices and trade volumes on environmental quality within the framework of the EKC hypothesis. In addition, by applying heterogeneous panel estimation methods of the mean group (group mean) variants, the effect of heterogeneity within the panel dataset is addressed. The group mean Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) estimation techniques applied in addition to mean group OLS estimator would help to eliminate serial correlation and endogeneity.

The succeeding sections of this study are arranged in the following order: a brief review of the extant literature underpinning renewable energy consumption and energy prices in the context of environmental degradation is highlighted in section 2. Section 3 presents the data and the empirical methodologies employed, while Section 4 details and discusses the estimated results and findings. Section 5 concludes by presenting policy implications and the direction for future studies.

## 2. Literature Review

While few studies (Al-Mulali and Ozturk, 2016; Balaguer and Cantavella, 2016) have both specifically examined the nexus of energy prices and the EKC hypothesis, the general concept of environmental degradation vis-à-vis $CO_2$ and energy consumption nexus has also been investigated in G-7 countries (Chang, 2015; Nabaee, Shakouri & Tavakoli, 2015; Shahbaz et al., 2017a). For instance, the concept was examined across 27 advanced economies including the G-7 and found that $CO_2$ was cointegrated with real Gross Domestic Product (GDP), disaggregate energy consumption, trade openness, urbanization, and energy prices (Al-Mulali and Ozturk 2016). The study showed that GDP increases the $CO_2$ emissions and confirmed an inverted U-shaped relationship between the GDP and $CO_2$ emissions, whereas, Usman et al. (2019b) noted that stimulating environmental performance reduces growth in 28 European Union (EU) countries.

Adding to the evidence of the EKC hypothesis, Balaguer and Cantavella (2016) specifically investigated the EKC hypothesis for Spain (one of the 27 advanced economies) over the period 1874-2011. The study found that 1950 related emissions in Spain were 24 times more than in 1874; however, emissions generated in 2011 were 250 times higher compared with the 1874 $CO_2$ emissions. In the wake of the historical observations, the study also observed that the per capita income of Spain might have attained a certain level, thus causing a decline in $CO_2$ emissions since the per-capita income was observed to have experienced a 50% increase in growth rate in 1950 than in 1874. Importantly, the validity of the EKC hypothesis was confirmed for Spain when energy prices were incorporated in the estimation model of the Autoregressive Distributed Lag (ARDL) approach (Balaguer and Cantavella 2016). The level of per capita income in Spain corresponded to the highest $CO_2$ emissions in 1980 before experiencing a decline in $CO_2$ emissions with increasing income growth. However, while Balaguer and Cantavella (2016) employed real oil prices as a proxy variable for energy price, Al-Mulali and Ozturk (2016) employed a weighted average of the index of gas prices, liquid fuel and energy heat prices.

The findings from the drivers of renewable energy consumption in G7 countries showed that $CO_2$ emissions and income had a significant positive relationship with renewable energy at the panel level while the relationship with oil price was insignificantly negative with renewable energy at the panel level. However, country-level estimations showed that apart from income with a robust positive relationship across all countries, estimates for oil price and $CO_2$ emissions were disparate across countries (Sadorsky 2009). In contrast to the theoretical framework of previous studies, we account for the reverse effects of renewable energy, energy prices and trade on $CO_2$ emissions within the EKC framework.

A recent study by Yilanci and Ozgur (2019) employed per-capita ecological footprint (EF) in lieu of the conventional $CO_2$ emissions as a proxy for environmental degradation to investigate the EKC hypothesis in G-7 countries. The study equally analyzed the income-pollution level nexus in the sub-group periods. The findings confirmed the validity of the EKC hypothesis for Japan and the US, whereas no evidence of the EKC hypothesis was found for the other five countries. On the contrary, the validity of the EKC hypothesis was found only for Canada, France, Germany, Italy, the UK, and the US in the empirical study conducted by Shahbaz et al., (2017a). The results of this study also validated the feedback effect between $CO_2$ and GDP for France and Italy; a neutral effect for Japan while $CO_2$ emission was observed to Granger-cause GDP in Canada, Germany, the UK, and the US. While investigating the EKC hypothesis in G-7 countries, Chang (2015) and Nabaee, Shakouri and Tavakoli (2015) compared their outcomes with the BRICS (Brazil, Russia, India, China, and South Africa) countries and selected developing countries and found while G-7 countries are on the verge of decarbonizing their economy, BRICS and developing countries are still carbonizing and intensifying its energy-based economy.

The EKC hypothesis in a panel of G-7 countries over the period 1991-2008 was investigated by considering potential endogeneity biases (Chiang and Wu 2017). With the implementation of the panel smooth transition regression approach, the study examined the changes in the elasticity of $CO_2$ emissions with country and time to underpin the elasticity of heterogeneous countries and possible structural breaks. The $CO_2$-real income per capita (GDP per capita) nexus in Japan, the UK, and the US favoured environmental quality while such relationship was not valid for remaining G-7 countries. However, an inverted U-shaped relationship between $CO_2$ emissions and real income per capita was validated at a turning of US$ 20,488. Hence, affirmed the regime-switching impact of GDP per capita —the EKC hypothesis on environmental degradation vis-à-vis $CO_2$ emissions in the panel of G-7 countries.

The role of renewable energy consumption in the context of the EKC hypothesis was examined in a panel of G-7 countries over the period 1991-2016 (Raza and Shah, 2018). While investigating the EKC hypothesis, the study employed the dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and the fixed effect ordinary least squares regression (FE OLS) to establish evidence of cointegration. The study found economic growth to increase $CO_2$ emissions, thus, causing more environmental hazards, especially in the long-run. In the case of renewable energy consumption, the development of the renewables in the panel of G7 countries was a significant factor for long-term decarbonization policy. While incorporating trade indicator together with renewable energy consumption and per capita GDP, the empirical results supported the validity of the EKC hypothesis in G-7 countries. Among other studies that have either examined the EKC hypothesis for the panel of G-7 countries or individual G-7 member countries in the framework of alternative energy source include Sebri and Ben-Salha (2014); Shafiei and Salim, (2014); Zoundi, (2017); Ito, (2017); Shahbaz et al., (2017b); Cetin (2018); Cai et al., (2018); Lau et al., (2019). The results of these studies largely support the $CO_2$-mitigating effect of renewable energy consumption. However, most of these studies failed to control for energy price effects, which may have far-reaching implications for environmental quality. In view of the few studies that incorporate energy prices, one major challenge stands out, the analysis of panel data covering larger geographical locations may not accurately depict the true relationship amongst the variables in the individual countries of the panel employed. Conversely, studies on a single country are geographically limited, hence, policy implications may be country-specific. In contrast, our study moves a step further by incorporating heterogeneous panel and country-specific cointegration and estimation techniques in order to unravel the long-run relationship between renewable energy consumption, trade, income, energy prices and $CO_2$ emissions in the G-7 countries as a whole, as well as, for individual member countries.

## 3. Material and Methods

### *3.1 Data*

We used an unbalanced panel dataset sampled at different time periods for the United Kingdom (1970-2014) and Germany (1990-2014) due to data limitations in these countries. Data for the remaining 5 countries in the panel were sampled from 1960-2014. Variables such as $CO_2$ (measured in metric tons per capita), per-capita real GDP (measured in constant 2010 USD), renewable energy consumption (measured in kg of oil equivalent per capita), per capita trade volume (measured in constant 2010 USD) are obtained from the World Bank world development indicators[4]. The energy price index follows the United Nations classification of individual consumption by purpose which was adopted in the compilation of the Harmonized Index of Consumer Prices (HICP) of the EU, the Euro area, as well as, OECD countries. The index includes

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[4] https://databank.worldbank.org

the COICOP 04.5 classification (Electricity, gas and other fuels) which incorporates the weighted index of the price of electricity, gas, natural gas and town gas, liquefied hydrocarbons, domestic heating and lighting oils, solid fuels and heat energy. It also includes the COICOP 07.2.2 classification which covers fuels (diesel and petrol) and lubricants for personal transport equipment. The energy price index was obtained from the OECD Statistics[5].

### *3.2 Model Estimation*

In line with the purpose of this research, the conventional EKC model was augmented with renewable energy, energy prices and trade, specified as (Grossman and Krueger 1991, 1995);

$$LCO2PK_{it} = \beta_0 + \beta_1 LRGDPK_{it} + \beta_2 LRGDPK2_{it} + \beta_3 LRENPK_{it} + \beta_4 LCPIE_{it} + \beta_5 LTRADPK_{it} + u_{it} \tag{1}$$

From equation (1), *LCO2PK*, *LRGDPK*, *LRGDPK2, LRENPK, LCPIE* and *LTRADPK* denotes respectively, the real per-capita GDP, the square of real per capita GDP, per capita renewable energy consumption, energy prices and per capita trade volume of country *i* at time *t*, *u* denotes the stochastic white noise error term. $\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$ and $\beta_5$ indicate the slope coefficients of the variables while $\beta_0$ is a time-invariant country-specific effect. Except for energy prices, all quantitative variables are measured in per-capita terms in order to control for population effects. All variables including energy prices were log-transformed in order to reduce the incidence of heteroscedasticity consequently, slope coefficients are interpreted as elasticities.

We used heterogeneous panel estimation methods of the mean group (group mean) variants because of the unbalanced nature of the dataset employed. Unlike conventional pooled panel

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[5] http://www.oecd.org/sdd

estimation procedures, panel mean group estimation techniques employ full heterogeneity with the implication of both long-run and short-run heterogeneity. In the estimation of the mean group, N time series equations were estimated for each individual country in the panel. The estimated coefficients were then averaged to represent the overall panel estimate. The estimation sequence of mean group techniques makes them ideal for unbalanced panel data of the type applied in the present study. We used the group mean FMOLS (Pedroni 2001a, 2001b), DOLS (Kao and Chiang, 2001; Pedroni, 2001b) and mean group estimator (Peseran and Smith, 1995). While the FMOLS procedure eliminates serial correlation and endogeneity in OLS estimations through a semi-parametric correction, the DOLS procedure conversely applies a parametric correction to OLS estimators to eliminate endogeneity and serial correlation. The DOLS model is argued to exhibit the least bias in small samples when compared to the FMOLS and the OLS procedures (Kao and Chiang, 2001). An advantage of group mean estimators over the other pooled panel estimators is that their formulation is based on the "*between dimension*" of the panel rather than the "*within dimension*" of pooled estimators, as such, the t-statistic implies a more flexible alternative hypothesis (Pedroni, 2001a). Pesaran and Smith (1995) further argued within the perspective of OLS regression that when the true slope coefficients are heterogeneous, group mean estimators provide a consistent sample mean point estimates of the heterogeneous cointegrating vectors, a feat which cannot be replicated by traditional pooled estimators. All three estimation procedures are used to ascertain whether the model parameters are robust to different estimation techniques.

The panel vector error correction model (VECM) is a suitable Granger causality testing approach to apply when the variables are integrated of order one, I(1) and long-run cointegration has been validated among the series. In the present study, the panel VECM was used to test both the long-run and short-run Granger causality relationship, specified as:

$$\Delta\begin{bmatrix} LCO2PK_{it} \\ LCPIE_{it} \\ LRENPK_{it} \\ LRGDPK_{it} \\ LRGDPK2_{it} \\ LTRADPK_{it} \end{bmatrix} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \\ \beta_6 \end{bmatrix} + \sum_{k=1}^{p} \Delta \begin{bmatrix} \theta_{11ik}\theta_{12ik}\theta_{13ik}\theta_{14ik}\theta_{15ik}\theta_{16ik} \\ \theta_{21ik}\theta_{22ik}\theta_{23ik}\theta_{24ik}\theta_{25ik}\theta_{26ik} \\ \theta_{31ik}\theta_{32ik}\theta_{33ik}\theta_{34ik}\theta_{35ik}\theta_{36ik} \\ \theta_{41ik}\theta_{42ik}\theta_{43ik}\theta_{44ik}\theta_{45ik}\theta_{46ik} \\ \theta_{51ik}\theta_{52ik}\theta_{53ik}\theta_{54ik}\theta_{55ik}\theta_{56ik} \\ \theta_{61ik}\theta_{62ik}\theta_{63ik}\theta_{64ik}\theta_{65ik}\theta_{66ik} \end{bmatrix} \times \begin{vmatrix} LCO2PK_{it-k} \\ LCPIE_{it-k} \\ LRENPK_{it-k} \\ LRGDPK_{it-k} \\ LRGDPK2_{it-k} \\ LTRADPK_{it-k} \end{vmatrix}$$

$$+ \begin{bmatrix} \lambda_{1i} \\ \lambda_{2i} \\ \lambda_{3i} \\ \lambda_{4i} \\ \lambda_{5i} \\ \lambda_{6i} \end{bmatrix} ECT_{it-1} + \begin{bmatrix} u_{1it} \\ u_{2it} \\ u_{3it} \\ u_{4it} \\ u_{5it} \\ u_{6it} \end{bmatrix} \qquad (2)$$

Where $ECT_{t-1}$ is the lagged residual from the long-run relationship, Δ is the difference operator and $u_{xit}$ is the stochastic error term at time $t$ in the $x^{th}$ equation of the $i^{th}$ country, which is independently and identically distributed (i.i.d). The significance of the estimated coefficient of the $ECT_{t-1}$ in any equation indicates the validation of the long-run causality from the independent variables to the dependent variable of the specific equation. For instance, $\lambda_{1i} \neq 0$ implies that the long-run causality runs from the regressors to *LCO2PK*. The short-run causality is depicted by the joint statistical significance of the lagged differences of the explanatory variables. For instance, $\sum_{k=1}^{p} \Delta\theta_{12ik} \neq 0$ implies that *LCPIE* has a short-run predictive content for *LCO2PK.*

### *3.3 Descriptive Statistics*

A cursory look at the summary statistics shows that while log-transformed real per-capita GDP (LRGDPK) has the lowest standard deviation and thus, the least volatile of all the variables, its squared counterpart (LRGDPK2), however, is the most volatile with the highest standard deviation. This implies that the EKC inflexion points would most likely be disparate across countries. Per-capita renewable energy consumption follows suit with the 2nd most volatile variable in the dataset signifying potential differences in the attitude of stakeholders towards the production and utilization of renewable energy in their respective economies. It can be observed from Figure 1 that per capita $CO_2$ emissions for all countries is initially upward sloping from the beginning of the 1960s. The downward sloping of the trend occurs during the mid-part of the 2000s, a period which coincides with the institutionalization of the Kyoto protocol in February 2005. The time-series plot of energy prices shows a level convergence across the G-7 countries. A major reason for this may be attributed to the regional economic integration of the EU which was aided by the introduction of the Euro as a single currency for the EU member countries. In line with the law of one price, Euro area price convergence with other advanced economies such as the US has been validated in various studies (Sosvilla-Rivero & Gil-Pareja, 2004; Goldberg & Verboven, 2005; Rogers, 2007). The implication of this observation is that energy price effects across G-7 countries may not be too far apart.

***INSERT TABLE 1 HERE***

***INSERT FIGURE 1 HERE***

## 4. Results and discussions

Prior to estimating the model coefficients, we employ several pretesting procedures to ascertain the time series properties of the variables as well as the status of cointegration. We use country-specific and panel unit root techniques, and country-specific and panel cointegration techniques. Detailed results are outlined in subsequent sub-sections.

### *4.1 Unit root and stationarity test results*

We use the Dickey-Fuller generalized least squares (DFGLS) (Elliot et al., 1996) as well as the Kwaitkowski-Phillips-Schmidt-Shin (KPSS) (Kwaitkowski et al, 1992) stationarity test in order to ascertain the country-specific time series properties of the variables. A rejection of the null hypothesis of the DFGLS unit root test implies variable stationarity, however, a rejection of the null hypothesis of the KPSS stationarity test implies that the variable is non-stationary. Results of the unit root and stationarity tests are outlined in Table 2. From Table 2, the KPSS stationarity test rejects the null hypothesis of stationarity for all variables at levels in all 6 countries at all conventional significance levels. This is also corroborated by the DFGLS unit root test in which the null of a unit root cannot be rejected for all variables at levels in all 6 countries at the 1% significance levels. After first differencing the variables, the KPSS stationarity test fails to reject the null of stationarity at either the 1% or 5% significance levels for all variables in all countries. The DFGLS unit root test also rejects the null of a unit root at either the 1% or 5% or 10% significance level for all variables in all countries. Going by the results obtained by the stationarity and unit root test, it is safe to infer that all the variables are I(1), thus, employing conventional panel estimation techniques may yield spurious results if the variables are not cointegrated. Against this backdrop, it is now appropriate to undertake panel and country-specific cointegration tests.

***INSERT TABLE 2 HERE***

### *4.2 Cointegration test results*

In order to ascertain the existence of a non-spurious long-run relationship between the variables, we use the Fisher and Johansen panel and country-specific cointegration test procedure. In this procedure, the p-values of the Johansen maximum likelihood cointegration test statistics (Johansen and Juselius, 1990) are aggregated via the Fisher test (see Maddala and Kim; 1998, p. 137). The test statistic can be computed as $-2\sum_{i=1}^{N} logp_i \sim\chi_{2N}^2$ where $p_i$ indicates the p-value of the Johansen test statistic for the *ith* country. The test assumes heterogeneity of coefficients across countries. In Table 3, we fail to reject the hypothesis of at most 3 cointegrating relationships at 5% and 1% significance level of the whole panel. In Table 4 of the country-specific statistics, it is observed that the null hypothesis of no cointegration for each country is rejected at 5% significance level for Japan and the UK and rejected at 1% significance level for the remaining countries under the maximum Eigenvalue statistic. The hypothesis of at most 1 cointegrating relationship cannot be rejected for the US and Japan at 1% and 5% significance levels, respectively under the maximum Eigenvalue statistic. However, the hypothesis of at most 2 cointegrating relationships cannot be rejected for the remaining countries under the maximum eigenvalue statistic. After validating panel and country-specific cointegration, we progress to estimate the panel and country-specific long-run coefficients.

***INSERT TABLE 3 HERE***

***INSERT TABLE 4 HERE***

### *4.3 Estimation results*

The results of the mean group OLS, group mean FMOLS and group mean DOLS estimators are outlined in Table 5. The EKC hypothesis is validated in all panel estimation specifications. Energy price has a robust negative relationship with $CO_2$ emissions in all the 3 panel estimators. In the mean group OLS specification, a 1% increase in energy prices reduces $CO_2$ emissions by about 0.23%, in the FMOLS specification, the same increment declines $CO_2$ emissions by 0.23%. However, in the group mean-DOLS specification, $CO_2$ emissions declines by 0.17%, which is not too far from the estimates of the other specifications. The outcome is consistent with Balaguar and Cantavella (2016) and Al-mulali and Ozturk (2016). We observe that the estimates for the mean group OLS as well as the group mean FMOLS specifications corresponding to the coefficients for renewable energy are quite close but quite different from that which is obtained from the group mean DOLS specification. A 1% increase in renewable energy consumption leads to a 0.08% reduction in the mean group OLS specification and a 0.09% reduction in the group mean FMOLS specification. The group mean DOLS, however, supports a 0.26% reduction in $CO_2$ emissions for a 1% increase in renewable energy consumption, consistent with Usman et al., (2020) who found a negative effect of renewable energy on environmental degradation in the US. A significantly negative relationship between renewable electricity consumption and $CO_2$ emissions was uncovered in Al-mulali and Ozturk (2016). Going further, a 1% increase in international trade volumes triggers an increase in $CO_2$ emissions by 0.20% for the mean group OLS specification, a 0.21% reduction for the group mean FMOLS and a 0.19% reduction in the group mean DOLS specification. This outcome is inconsistent with Al-mulali and Ozturk (2016), where a negative relationship between trade openness and $CO_2$ emissions was found for 27 advanced economies.

Based on the country-specific estimations, the results show that the EKC hypothesis is supported in all countries, for all specifications and that energy prices have a significant negative effect on $CO_2$ emissions. The EKC turning points, the magnitude of the energy price effects, and the effect of renewable energy consumption and trade volumes are however disparate across countries. The subsequent sub-sections discuss the country-specific results in details.

***INSERT TABLE 5 HERE***

*Estimation results for Canada*

For Canada, a 1% increase in energy prices leads to 0.166% and 0.165% reduction in $CO_2$ emissions in both OLS and FMOLS specifications as well as 0.188% reduction in the DOLS specification. This is consistent with He and Richard (2010), where a negative relationship between oil and $CO_2$ emissions was uncovered for Canada – though with a lot lesser magnitude of 0.28% reduction for a 10% increase in emissions. However, while He and Richard (2010) adopted oil prices, this study adopts a weighted index of energy prices. Renewable energy consumption, on the other hand, has an insignificant effect on $CO_2$ emissions, consistent with Bilgili et al. (2016), where an insignificant relationship between renewables and $CO_2$ emissions was found for Canada via a DOLS estimation. This may have arisen due to Canada's renewed dependence on fossil fuels, which necessitated the drop out from the Kyoto protocol. Trade volume effect is insignificant for both the OLS and DOLS models but is statistically significant in the FMOLS model where a 1% increase in trade volume increases $CO_2$ emissions by 0.101%.

*Estimation results for France*

In France, a different scenario is observed as energy prices seem to have a relatively larger effect on $CO_2$ emissions compared to Canada. A 1% rise in energy prices leads to 0.261%, 0.307% and 0.311% reduction in $CO_2$ emissions with the OLS, FMOLS and DOLS specifications, respectively. This relationship is novel in the literature for the French regarding the inclusion of energy prices. The effect of renewable energy on $CO_2$ emissions has no statistical evidence for all 3 specifications — an outcome consistent with Bilgili et al. (2016). This implies that the taxation of fossil fuels in France is a more viable method of mitigating $CO_2$ emissions. Trade volume has a statistically significant positive relationship with $CO_2$ emissions as evinced from all specifications.

Specifically, a 1% increase in trade leads to a reduction in $CO_2$ emissions by 0.650% for both OLS and FMOLS specifications and a reduction of 0.547% in the DOLS specification.

*Estimation results for Germany*

For Germany, renewable energy consumption has a negative relationship with $CO_2$ emissions in all 3 specifications but only significant in the DOLS specification. A 1% rise in renewable energy consumption leads to 1.715% reduction in $CO_2$ emissions based on the DOLS specification. Energy prices are significantly negative and near-identical relationship in both FMOLS and DOLS specifications, reducing $CO_2$ emissions by ~0.243% at a 1% rise in energy prices in both specifications. This gives credence to the viability of taxing fossil fuels as a means of mitigating $CO_2$ emissions in Germany. Trade volume has a significant positive impact on $CO_2$ emissions in both the FMOLS and DOLS specifications, increasing $CO_2$ emissions by 0.380% and 0.831% at 1% increase in trade volume for both the FMOLS and DOLS models respectively. The EKC hypothesis is validated in only the DOLS specification unlike the observed outcome in other countries validating the EKC hypothesis in all model specifications. A cautious interpretation is required in this situation because of the shorter time series (1991-2014) employed for the German case estimation, which may have influenced the sensitivity of coefficients using different estimation techniques. A significant negative relationship between energy prices and carbon emissions in Germany shows the importance of fossil fuel taxation in mitigating carbon emissions, constituting a new finding in the literature.

*Estimation results for Italy*

In the Italian model, there is a significant negative relationship between energy prices and $CO_2$ emissions in all 3 specifications. A 1% rise in energy prices lead to 0.272% reduction in $CO_2$

emissions for both OLS and DOLS specification and 0.284% reduction in $CO_2$ emissions for the FMOLS specification. Renewable energy consumption has a significant negative relationship with $CO_2$ emissions in all 3 specifications. A 1% increase in renewable energy consumption leads to 0.125%, 0.146% and 0.121% reduction in $CO_2$ emissions in the OLS, FMOLS and DOLS specifications respectively. This outcome is inconsistent with Bilgili et al. (2016), where an insignificant relationship was found between renewable energy consumption and $CO_2$ emissions. But consistent with Bento and Moutinho (2016) wherein a significant negative relationship was found between renewable electricity consumption and $CO_2$ emissions in Italy. This new finding shows that Italy is quite advanced in the deployment of alternative cleaner energy sources and shows a clearer and more definitive detail on the effectiveness of both renewable energy and increased energy prices in mitigating carbon emissions in Italy. Trade volume, however, has no significant relationship with $CO_2$ emissions in all specifications — an outcome that is inconsistent with Bento and Moutinho (2016) in which a significantly positive relationship was established between international trade and $CO_2$ emissions.

*Estimation results for the United Kingdom*

The results for the United Kingdom are a bit similar to what has previously been obtained in Italy — as energy prices and renewable energy consumption both significantly decline $CO_2$ emissions. A 1% rise in energy prices causes 0.198%, 0.212% and 0.175% decline in $CO_2$ emissions for the OLS, FMOLS and DOLS specifications respectively. In addition, a 1% rise in renewable energy consumption leads to 0.140%, 0.203% and 0.149% reduction in $CO_2$ emissions for the OLS, FMOLS and DOLS specifications whereas the effect of trade volume, on the other hand, is negative in all the specifications but statistically insignificant. This shows that just like Italy, the UK’s attitude towards deploying alternative energy sources seems quite uncompromising.

### *Estimation results for the United States*

Going by its status as the world's biggest economy, the energy demand of the US would be enormous, which may lead to difficulties in sustaining lower $CO_2$ emissions. It can, however, be observed from the estimated coefficients that increasing energy prices are more effective in reducing $CO_2$ emissions than increasing renewable energy consumption. Particularly, a 1% increase in energy prices declines $CO_2$ emissions by 0.225%, 0.216% and 0.194% in the OLS, FMOLS and DOLS specifications respectively. The effect of renewable energy consumption is negative in all specifications but significant only for the OLS specification at a 10% level. A 1% rise in renewable energy consumption leads to 0.082% reduction in $CO_2$ emissions as evinced from the OLS specification. Trade volume shows a significantly positive relationship with $CO_2$ emissions for both the OLS and FMOLS specifications. Thus, a 1% rise in trade volume leads to 0.313% and 0.224% reduction in $CO_2$ emissions in both the OLS and FMOLS specifications, contrary to a statistically insignificant positive coefficient with the DOLS specification.

### *Estimation results for Japan*

The estimated results for Japan show that energy prices are more effective in reducing $CO_2$ emissions, evidenced in a significant negative coefficient of energy prices compared to an insignificant negative coefficient of renewable energy consumption in all 3 specifications. A 1% increase in energy prices leads to 0.211%, 0.212% and 0.227% decline in $CO_2$ emissions for the OLS, FMOLS and DOLS specifications. Trade has a significantly positive relationship with $CO_2$ emissions only in the OLS specification, reducing $CO_2$ emissions by 0.142% at 1% increase in trade volume. The effect of trade volume on $CO_2$ emissions is however positive but insignificant for FMOLS and DOLS models.

### *4.4 Panel Granger causality test results*

From the results of the long-run segment of the panel Granger causality tests outlined in Table 6, it can be observed that the long-run causality is validated for all the variables, with LRGDP and its quadratic counterpart having the fastest speed of adjustment. About 99% deviation of GDP from its equilibrium values are corrected yearly. Energy prices have the slowest speed of adjustment, a 20% deviation from its equilibrium values is corrected yearly, attributable to nominal price rigidities. Renewable energy consumption has a modest speed of adjustment compared to other adjustment speeds in the model, with 24% deviation from its equilibrium path adjusted yearly. This implies that renewable energy consumption and energy prices are the most exogenous variables in the model. The adjustment parameter for trade volume and $CO_2$ emissions are quite sizable — 62.20% and 57.20% respectively. From the results of the short-run causality, we observe a causality flowing from energy prices, GDP, quadratic GDP and trade to $CO_2$ emissions. Renewable energy consumption, however, has no short-run predictive content for $CO_2$ emissions. It can observed that trade volume, renewable energy consumption and GDP has short-run predictive content for energy prices. However, $CO_2$ emissions have no short-run predictive content for energy prices implying that energy prices are affected by economic shocks rather than shocks to the environment. In summary, a unidirectional causality is observed flowing from energy prices to $CO_2$ emissions, from GDP and quadratic GDP to $CO_2$ emissions and from trade volume to $CO_2$ emissions. A unidirectional causality is similarly observed from GDP and quadratic GDP to energy prices and from renewable energy to energy prices with the implication that renewable energy consumption has no direct impact on $CO_2$ emissions through its direct effect on energy prices. Bidirectional causality is observed between energy prices and trade volume with the implication that energy price convergence across the G-7 countries is as a result of trade instigated economic integration within the region. Bidirectional causality is likewise found between trade volume and GDP which shows a strong interdependence between trade and output in the G-7 economies. GDP and its quadratic counterpart have a unidirectional causal flow towards renewable energy consumption, implying that economic growth exacts pressure on renewable energy consumption due to the environmental consequences of growth instigated high energy needs. This consequently leads to the need to seek out alternative cleaner energy sources.

***INSERT TABLE 6 HERE***

### *4.4 Discussion of major findings*

As reported in section 4.3, while trade volumes spur $CO_2$ emissions, renewable energy consumption and energy prices tend to dampen it. This finding is consistent with Dogan and Seker (2016) who established that renewable energy mitigates environmental pollution in the EU but disagreed with the notion that trade increases emissions. Our finding on the negative effect of renewables and energy prices on $CO_2$ emissions is corroborated by Al-mulali and Ozturk (2016) while the insignificant effect of renewables on $CO_2$ emissions is line with Bilgili et al. (2016) who found a negative and insignificant impact of renewable energy on $CO_2$ emissions in Canada. The results further revealed that the effect of energy prices in reducing $CO_2$ emissions is stronger relative to renewable energy, which is relatively disparate across countries. This could be occasioned by the different attitudes of country-specific stakeholders in harnessing and distributing renewable energy in the various countries. For instance, due to high energy demand and renewed fossil fuel dependence traceable to oil sands and shale oil boom in Canada and the US, phasing out fossil fuel energy sources may not be in the best economic interest of these countries.

Therefore, the United States had to pull out of the Kyoto protocol in 2001 while Canada dropped out in December 2012. Out of the remaining countries which ratified the Kyoto protocol on climate change in the G-7, only Italy, the UK and Germany which apart from France constitutes the European bloc of the G-7, have renewable energy consumption evidently providing pollution abatement effects. However, the pollution abatement effect of energy prices is robust across all countries regardless of the estimation techniques. This further reveals that the attitude of different countries in the utilization of renewable energy is quite different depending on the political climate. In the US, renewable energy has been quite politicized because of the notion of renewable energy curtailing economic growth. In contrast, the more liberal segment perceives the utilization of renewable energy as a way to protect the environment and foster sustainable economic growth regardless of the trade-off. Countries like the US and Canada are both oil-producing and both make up the North American bloc of the G-7. This shows a significant difference in perspective on the issue of climate change mitigation moving from the Europe to North America. The different perspectives appear both politically and economically motivated. The negative effect of renewable energy on $CO_2$ emissions in both Italy and the UK and to a lesser extent in Germany speaks volumes of the significant difference across continents in the climate change debate and the need to search for reasonable ways to bridge this gap

The positive effect of trade on $CO_2$ emissions can be traceable to the measurement of trade used in this study which is trade volume (export+import). Our finding is supported by Farhani and Ozturk (2015), Dogan and Turkekul (2016) and Ozatac et al. (2017). The validity of the EKC hypothesis is not entirely in line with the previous studies. For example, Shahbaz et al. (2017a) confirms evidence of the EKC hypothesis for six countries excluding Japan. In a recent study, Yilanci and Ozgur (2019) confirms the validity of the EKC hypothesis for Japan and the US while no evidence of EKC is found in the remaining five countries of the G-7 bloc. Regarding the findings of the panel Granger causality test, renewable energy Granger-cause energy prices, while energy prices Granger-cause $CO_2$ emissions. By implication, the synergy between harnessing renewable energy sources and the imposition of fossil fuel taxes in order to forestall climate change and further environmental degradation exists in some members of the G-7 countries. Therefore, the result is not supported by the earlier empirical result outlined in Dogan and Seker (2016) who confirms a bidirectional causality between renewable energy consumption and $CO_2$ emissions, and causality running from economic growth to $CO_2$ emissions. The inconsistency between existing studies can be traced to the inability to control for the effect of full heterogeneity in the estimation procedures. Our dataset was able to maintain its unique characteristics because of the unbalanced nature, hence, there was no need to symmetrically adjust the dataset into a more uniform quality, an act that would further constitute the loss of valuable data. The effect of full heterogeneity in the panel and time series data of our study was captured through the mean group and group mean methods of the panel, as well as, time series estimation.

## 5. Conclusion and policy implications

We employed a fully heterogeneous panel and country-specific estimation techniques in order to unravel the long-run equilibrium and the causal relationship amongst energy prices, renewable energy consumption, $CO_2$ emissions, trade volume. The study likewise tested the validity of the environmental Kuznets curve hypothesis in G-7 countries. The empirical results showed that renewable energy consumption and energy prices dampen the pressure on $CO_2$ emissions, but trade volumes positively exert pressure on $CO_2$ emissions. Based on the country-specific estimation results, a negative effect of energy prices on $CO_2$ emissions was found while the validity of the environmental Kuznets curve hypothesis was confirmed at both panel and country-specific levels. Conclusively, energy prices had a stronger effect on the reduction of $CO_2$ emissions compared to renewable energy consumption. While the pollution abatement effect of renewable energy consumption was observed for the whole panel, individual estimations showed that the effect of renewable energy consumption was quite disparate across the G-7 countries. The results based on a Panel Granger causality test showed a uni-directional causality running from energy prices, GDP, the quadratic term of GDP and trade to $CO_2$ emissions. The results further revealed no evidence to support the causal relationship between renewable energy consumption and $CO_2$ emissions, however, renewable energy consumption was found to indirectly affect $CO_2$ emissions through its direct effect on energy prices.

On policy directive, the synergy can be enhanced by formulating a tax program wherein the tax on fossil fuels would be directly proportional to the availability of renewable energy sources, as renewable energy rises steadily, taxes on conventional energy sources must be increased until renewable energy becomes economically viable compared to fossil fuels. An application of this synergy in all countries would greatly reduce the pressure on the environment and significantly improve worldwide environmental sustainability in both short- and long- run. This is a clear pathway towards the attainment of the United Nations Sustainable Development Goals (SDGs). Considering the commitment of the EU countries within the G-7 to set-up active renewable energy policies such as the revised renewable energy directive 2018/2001/EU[6], the commitments of the G-7 member countries could be harmonized toward attaining feasible and collective targets without undermining country-specific potentials. It can be observed that the policy implication of

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[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

this study cannot follow a one-size-fit all approach due to the disparate distribution of inferences across the G7 countries regarding renewable energy consumption. Employing full heterogeneity, as well as, individual time series estimations has succinctly shown that things are not very rosy in the renewable energy department of the US and Canada. As the US happens to be the second-highest polluting economy after China, there is the need to de-politicize climate change and adopt renewable energy in the two North American countries. More effort should be put in place to educate the populace on the dangers of climate change. The strides taken by the EU countries should not be dampened by political rhetoric, as the consequence may constitute a significant danger for future generations.

Future studies should aim at country-specific causal relationships between renewable energy, energy prices and $CO_2$ emissions in order to ascertain the existence of synergy at the country level.

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Table 1: Summary Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| LCO2PK | 354 | 2.286567 | .4639481 | .7786112 | 3.113986 |
| LCPIE | 382 | 3.612786 | .8852169 | 1.460868 | 4.79814 |
| LRECNPK | 392 | 6.046653 | 1.13742 | 2.646366 | 7.715763 |
| LRGDPK | 382 | 10.28365 | .3676815 | 9.060408 | 10.85772 |
| LRGDPK2 | 382 | 105.8882 | 7.466323 | 82.09099 | 117.89 |

Source: Authors' computations.

Table 2: Stationarity and Unit root tests

| Countries | Panel A: Variables at Levels | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LCO2PK | | LCPIE | | LRENPK | | LRGDPK | | LTRADPK | |
| | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS |
| Canada | 0.423$^{a}$ | -1.129 | 0.476$^{a}$ | -1.223 | 0.687$^{a}$ | -0.764 | 0.459$^{a}$ | -1.207 | 0.364$^{a}$ | -1.768 |
| France | 0.374$^{a}$ | -0.901 | 0.559$^{a}$ | -1.081 | 0.669$^{a}$ | -0.786 | 0.607$^{a}$ | -0.409 | 0.515$^{a}$ | -1.347 |
| Germany | 1.66$^{a}$ | -2.709 | 0.357$^{a}$ | -2.098 | 0.681$^{a}$ | -0.690 | 0.484$^{a}$ | -1.639 | 0.291$^{a}$ | -3.124$^{c}$ |
| Italy | 0.504$^{a}$ | 0.127 | 0.543$^{a}$ | -1.068 | 0.596$^{a}$ | -0.758 | 0.643$^{a}$ | -0.048 | 0.495$^{a}$ | -1.000 |
| United Kingdom | 0.285$^{a}$ | -0.951 | 0.387$^{a}$ | -1.624 | 0.478$^{a}$ | -1.133 | 0.326$^{a}$ | -2.057 | 0.280$^{a}$ | -2.484 |
| United States | 0.367$^{a}$ | -1.537 | 0.335$^{a}$ | -1.754 | 0.683$^{a}$ | -0.827 | 0.435$^{a}$ | -1.502 | 0.486$^{a}$ | -1.684 |
| Japan | 0.441$^{a}$ | -0.979 | 0.532$^{a}$ | -1.374 | 0.560$^{a}$ | -0.808 | 0.628$^{a}$ | -0.584 | 0.322$^{a}$ | -2.263 |
| Countries | Panel B: Variables at First Difference | | | | | | | | | |
| | D.LCO2PK | | D.LCPIE | | D.LRENPK | | D.LRGDPK | | D.LTRADPK | |
| | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS | KPSS | DFGLS |
| Canada | 0.398$^{c}$ | -4.811$^{a}$ | 0.149 | -3.184$^{a}$ | 0.430$^{c}$ | -3.981$^{a}$ | 0.418$^{c}$ | -4.784$^{a}$ | 0.263 | -5.152$^{a}$ |
| France | 0.415$^{c}$ | -4.270$^{a}$ | 0.180 | -3.355$^{b}$ | 0.408$^{c}$ | -4.006$^{a}$ | 0.431$^{c}$ | -4.812$^{a}$ | 0.309 | -5.501$^{a}$ |
| Germany | 0.414$^{c}$ | -3.365$^{b}$ | 0.101 | -3.594$^{b}$ | 0.414$^{c}$ | -4.063$^{a}$ | 0.417$^{c}$ | -6.233$^{a}$ | 0.126 | -5.841$^{a}$ |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Italy | 0.634$^{c}$ | -2.879$^{b}$ | 0.203 | -3.502$^{b}$ | 0.461$^{c}$ | -5.414$^{a}$ | 0.464$^{c}$ | -5.837$^{a}$ | 0.431$^{c}$ | -6.337$^{a}$ |
| United Kingdom | 0.431$^{c}$ | -4.616$^{a}$ | 0.324 | -2.964$^{c}$ | 0.402$^{c}$ | -3.729$^{b}$ | 0.244 | -4.645$^{a}$ | 0.117 | -5.259$^{a}$ |
| United States | 0.343$^{c}$ | -4.732$^{a}$ | 0.104 | -3.735$^{b}$ | 0.347 | -2.853 | 0.418$^{c}$ | -4.829$^{a}$ | 0.330 | -5.108$^{a}$ |
| Japan | 0.432$^{c}$ | -2.627 | 0.168 | -4.074$^{a}$ | 0.418$^{c}$ | -4.956$^{a}$ | 0.426$^{c}$ | -4.538$^{a}$ | 0.217 | -5.112$^{a}$ |

Note: The table reports the Dickey-Fuller Generalized unit root test with the Elliot-Rothenberg-Stock(1996) interpolated critical values (DFGLS-ERS) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Stationarity test results for each country-specific variable at levels. The null hypothesis for DFGLS is the existence of a unit root which implies non-stationarity. The null hypothesis for KPSS is that the series is stationary. “$^{a}$”,”$^{b}$” and “$^{c}$” denotes statistical significance at the 1%, 5% and 10% levels respectively.

Table 3: Johansen and Fisher Unrestricted Cointegration Rank Test ($H_0$: No cointegration)

| Panel | Fisher Stat. | | Fisher Stat. | |
|---|---|---|---|---|
| Hypothesized No. of CE(s) | trace test | Prob. | max-eigen | Prob. |
| None | 195.0$^{***}$ | 0.0000 | 101.5$^{***}$ | 0.0000 |
| At most 1 | 107.0$^{***}$ | 0.0000 | 56.98$^{***}$ | 0.0000 |
| At most 2 | 58.64$^{***}$ | 0.0000 | 29.34$^{***}$ | 0.0094 |
| At most 3 | 38.70$^{***}$ | 0.0004 | 21.35$^{*}$ | 0.0929 |
| At most 4 | 29.84$^{***}$ | 0.0080 | 22.35$^{*}$ | 0.0717 |
| At most 5 | 29.25$^{***}$ | 0.0097 | 29.25$^{***}$ | 0.0097 |

Notes:’$^{***}$’and ’$^{*}$’ denotes statistical significance at the 1% and 10% levels respectively

Table 4: Johansen and Fisher Country Specific Statistics ($H_0$: No cointegration)

| Country | Trace | Prob. | Max-Eigen | Prob. |
|---|---|---|---|---|
| Canada | 183.6009$^{***}$ | 0.0000 | 83.8097$^{***}$ | 0.0000 |
| France | 155.4070$^{***}$ | 0.0000 | 62.9737$^{***}$ | 0.0000 |
| Germany | 144.9472$^{***}$ | 0.0000 | 48.3776$^{***}$ | 0.0047 |
| Italy | 143.9627$^{***}$ | 0.0000 | 46.1954$^{***}$ | 0.0091 |
| United Kingdom | 133.2015$^{***}$ | 0.0000 | 42.9367$^{**}$ | 0.0232 |
| United States | 124.6195$^{***}$ | 0.0001 | 52.6724$^{***}$ | 0.0012 |
| Japan | 126.8427$^{***}$ | 0.0001 | 45.0071$^{**}$ | 0.0129 |
| Hypothesis of at most 1 cointegrating relationship | | | | |
| Canada | 99.7911$^{***}$ | 0.0000 | 42.1215$^{***}$ | 0.0042 |
| France | 92.4334$^{***}$ | 0.0003 | 37.6373$^{**}$ | 0.0169 |
| Germany | 96.5696$^{***}$ | 0.0001 | 42.1582$^{***}$ | 0.0041 |
| Italy | 97.7673$^{***}$ | 0.0001 | 43.0538$^{***}$ | 0.0031 |
| United Kingdom | 90.2648$^{***}$ | 0.0005 | 37.2873$^{**}$ | 0.0188 |
| United States | 71.9471$^{**}$ | 0.0335 | 26.7706 | 0.2758 |
| Japan | 81.8356$^{***}$ | 0.0041 | 31.5820$^{*}$ | 0.0917 |
| Hypothesis of at most 2 cointegrating relationships | | | | |
| Canada | 57.6696$^{***}$ | 0.0046 | 23.1424 | 0.1675 |
| France | 54.7960$^{***}$ | 0.0097 | 20.3003 | 0.3207 |
| Germany | 54.4114$^{**}$ | 0.0107 | 25.3668$^{*}$ | 0.0936 |
| Italy | 54.7135$^{***}$ | 0.0099 | 26.0167$^{*}$ | 0.0782 |
| United Kingdom | 52.9775$^{**}$ | 0.0153 | 26.3967$^{*}$ | 0.0703 |
| United States | 45.1765$^{*}$ | 0.0874 | 23.8327 | 0.1407 |
| Japan | 50.2536$^{**}$ | 0.0292 | 24.7966 | 0.1092 |

Notes:’$^{***}$’and’$^{*}$’ denotes statistical significance at the 1% and 10% levels respectively

Table 5: Panel and country-specific estimation results

| Panel | | | |
|---|---|---|---|
| Variables | Mean Group OLS | Group Mean-FMOLS | Group Mean-DOLS |
| LCPIE | -0.225758$^{***}$ | -0.234366$^{***}$ | -0.169350$^{***}$ |
| LRENPK | -0.084570$^{***}$ | -0.093201$^{***}$ | -0.264111$^{***}$ |
| LRGDPK | 16.46624$^{***}$ | 8.156401$^{***}$ | 26.98987$^{***}$ |
| LRGDPK2 | -0.785871$^{***}$ | -0.397318$^{***}$ | -1.289601$^{***}$ |
| LTRADPK | 0.199876$^{*}$ | 0.205477$^{***}$ | 0.193246$^{***}$ |
| Canada | OLS | FMOLS | DOLS |
| LCPIE | -0.165598$^{***}$ | -0.165073$^{***}$ | -0.18810 $^{***}$ |
| LRENPK | -0.003313 | -0.001461 | 0.145211 |
| LRGDPK | 17.05942 $^{***}$ | 17.27092 $^{***}$ | 15.79845 $^{***}$ |
| LRGDPK2 | -0.790878$^{***}$ | -0.805969$^{***}$ | -0.728383$^{***}$ |
| LTRADPK | 0.053669 | 0.100522 $^{*}$ | 0.066165 |
| France | | | |
| LCPIE | -0.2614522$^{***}$ | -0.306934$^{***}$ | -0.310585$^{***}$ |
| LRENPK | -0.0283194 | -0.000760 | 0.034400 |
| LRGDPK | 22.949730 $^{***}$ | 21.07187 $^{***}$ | 19.75640 $^{***}$ |
| LRGDPK2 | -1.1651271 $^{***}$ | -1.072235$^{***}$ | -0.994348$^{***}$ |
| LTRADPK | 0.6500363 $^{***}$ | 0.654864 $^{***}$ | 0.546640 $^{***}$ |
| Germany | | | |
| LCPIE | -0.242736$^{***}$ | -0.243457$^{***}$ | 0.183390 |
| LRENPK | -0.215821 | -0.211918 | -1.71519 $^{***}$ |
| LRGDPK | -44.30459$^{*}$ | -48.65094 $^{**}$ | 94.84620 $^{**}$ |
| LRGDPK2 | 2.046318 $^{*}$ | 2.249479 $^{**}$ | -4.601248 $^{**}$ |
| LTRADPK | 0.371235 | 0.380486 $^{***}$ | 0.830798 $^{***}$ |
| Italy | | | |
| LCPIE | -0.2722195$^{***}$ | -0.284322$^{***}$ | -0.273339$^{***}$ |
| LRENPK | -0.1249403$^{***}$ | -0.146004$^{***}$ | -0.121201$^{**}$ |
| LRGDPK | 10.068650$^{***}$ | 9.773414$^{***}$ | 7.023427$^{***}$ |
| LRGDPK2 | -0.4246356$^{***}$ | -0.408180$^{***}$ | -0.271091$^{***}$ |
| LTRADPK | 0.0622173 | 0.070995 | -0.006995 |
| United Kingdom | | | |
| LCPIE | -0.1983623$^{***}$ | -0.212368$^{***}$ | -0.175060$^{***}$ |
| LRENPK | -0.1403334$^{***}$ | -0.203227$^{***}$ | -0.148706$^{*}$ |
| LRGDPK | 23.738801$^{***}$ | 32.47268$^{***}$ | 28.75883$^{***}$ |
| LRGDPK2 | -1.1350860$^{***}$ | -1.557730$^{***}$ | -1.375380$^{***}$ |
| LTRADPK | -0.113512 | -0.065921 | -0.168786 |

Notes:’$^{***}$’,’$^{**}$’, and’$^{*}$’ denotes statistical significance at the 1%, 5% and 10%  levels respectively

Table 5 contd. : Panel and country-specific Estimation results contd.

| Variables | OLS | FMOLS | DOLS |
|---|---|---|---|
| United States | | | |
| LCPIE | -0.222528$^{***}$ | -0.216244$^{***}$ | -0.194485$^{***}$ |
| LRENPK | -0.082263$^{*}$ | -0.068526 | -0.015279 |
| LRGDPK | 14.28918$^{***}$ | 14.88632$^{***}$ | 13.63381$^{***}$ |
| LRGDPK2 | -0.691411$^{***}$ | -0.713346$^{***}$ | -0.641208$^{***}$ |
| LTRADPK | 0.312883$^{***}$ | 0.223587$^{**}$ | 0.058092 |
| Japan | | | |
| LCPIE | -0.211497$^{***}$ | -0.212166$^{***}$ | -0.227266$^{***}$ |
| LRENPK | -0.013192 | -0.020514 | -0.028008 |
| LRGDPK | 11.25163$^{***}$ | 10.27055$^{***}$ | 9.111988$^{***}$ |
| LRGDPK2 | -0.526431$^{***}$ | -0.473241$^{***}$ | -0.415546$^{***}$ |
| LTRADPK | 0.141856$^{**}$ | 0.073805 | 0.026806 |

Notes:’$^{***}$’,’$^{**}$’, and’$^{*}$’ denotes statistical significance at the 1%, 5% and 10% levels respectively

Table 6: Panel Granger causality analysis (vector error-correction framework)

| Endogenous variables | ← Causal flow (Causing variables) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Short-run | | | | | | Long-run |
| | ΔLCO2PK | ΔLCPIE | ΔLRGDPK | ΔLRGDPK2 | ΔLRENPK | ΔLTRADPK | ECT$_{t\text{-}1}$ |
| ΔLCO2PK | — | 8.80$^{**}$ | 6.48$^{**}$ | 7.30$^{**}$ | 4.40 | 5.13$^{*}$ | -0.572$^{**}$ |
| ΔLCPIE | 4.46 | — | 5.01$^{*}$ | 4.86$^{*}$ | 6.16$^{**}$ | 13.33$^{***}$ | -0.200$^{**}$ |
| ΔLRGDP | 1.35 | 1.82 | — | 0.14 | 0.34 | 12.67$^{***}$ | -0.989$^{***}$ |
| ΔLRGDP2 | 1.33 | 1.23 | 0.39 | — | 0.52 | 13.22$^{***}$ | -0.992$^{***}$ |
| ΔLRENPK | 1.80 | 0.68 | 5.41$^{*}$ | 5.65$^{*}$ | — | 0.8348 | -0.246$^{***}$ |
| ΔLTRADPK | 3.25 | 32.44$^{***}$ | 44.74$^{***}$ | 46.63$^{***}$ | 4.35 | — | 0.622$^{***}$ |

*Notes*: ECT represents the coefficient of the error-correction term. Significance at the 1%, 5% and 10% levels are denoted by “$^{***}$”, “$^{**}$” and “$^{*}$” respectively. Numbers in the short-run cells indicate the $\chi^2$ statistics for the Wald tests of the null $H_0$: $\sum_{k=1}^{p} \theta_{jik} = 0$. Numbers in the long-run cells indicate the estimated adjustment parameter $\lambda_j$ under homogeneity assumption $\lambda = \lambda_i$. 2 lags were employed for the estimation based on the AIC and SBIC criterion.

**Figure 1**. Graphical plot of variables.