The role of globalization in CO_2 emissions: A semi-parametric panel data analysis for G7

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Abstract: In order to provide flexible and comprehensive results about the relationship between globalization and CO_2 emissions for the G7 countries, we introduce the KOF globalization index into traditional Stochastic Impacts by Regression on Population, Affluence and Technology model, and conduct the empirical analysis by applying a semi-parametric panel fixed effects model. The data covering the period of 1970-2015 consists of CO_2 emissions, KOF globalization index, renewable energy consumption and GDP. Our results indicate that the relationship between globalization and CO_2 emissions are inverted U-sharped, which strongly support the Environmental Kuznets Curve hypothesis. Furthermore, an increase of economic

output is associated with statistically significant growth in CO_2 emissions. On the contrary, an increment of renewable energy consumption lowers CO_2 emissions. Related policy proposals are then offered according to our empirical results.

Keywords: CO_2 emission; globalization; Environment Kuznets Hypothesis; Semi-parametric panel model

1. Introduction

CO_2 emissions (carbon emissions) have received tremendous attention since the signature of Kyoto Protocol because previous studies have revealed that carbon emissions are the decisive factors for global warming and climate change (Lashof and Ahuja, 1990; Solomon et al., 2009). The CO_2 emissions of the total world in 2018 amounted to 33890.80 million tonnes, which have increased by 1.37 times compared with the counterpart in 1970 (BP, 2018). Among all the countries, the G7 members[1] belong to great emitters. Specifically, the carbon emissions of the G7 countries were 8611.80 million tonnes in 2018, which accounted for 25.41% of the global emissions. In order to control global emissions, it is imperative to explore the influencing factors of the CO_2 emissions for the G7 countries.

The decisive factors of carbon emissions are widely discussed in previous studies. Some recent papers are listed in the Appendix A. As shown in Appendix A, the determinant factors of

Abbreviations: ADRL, auto regressive distributed lag; CE, CO_2 emissions per capita; DOLS, dynamic ordinary least squares; EKC, Environmental Kuznets Curve; FMOLS, fully modified ordinary least squares; GDP, GDP per capita; GMM, generalized method of moments; $KOFGI$, KOF Globalization Index; PLS, panel least squares; PMFE, parametric panel method with fixed effects; RE, renewable energy consumption per capita; STIRPAT, Stochastic Impacts by Regression on Population, Affluence and Technology; SPMFE, semi-parametric panel data method with fixed effects.

[1] The G7 members include the United States, United Kingdom, Germany, France, Japan, Italy and Canada.

carbon emissions include economic growth (denoted as GDP), renewable energy, globalization, urbanization, international trade, foreign direct investment, industrialization, R&D, democracy, income inequity, finance development, international tourism and so on. Among these factors, we concentrate our analysis on the impacts of globalization on CO_2 emissions for the G7 countries.

Globalization refers to the integration of different countries from economic, social and political aspects. With the development of technology, trade freedom, international finance and multinational operations of transnational corporations, globalization has been changing the world rapidly and thoroughly (Garrett, 2000). Plenty of scholars have investigated its impacts on economic growth, inequality, poverty and other consequences (Dreher et al., 2008; Gurgul and Lach, 2014; Ravallion, 2003). However, only a few scholars pay attention to its influences on the environment. Moreover, even in the previous studies which investigated the globalization's environmental impacts, the definition of globalization is incomplete. To be specific, previous studies usually focused on the economic aspects of globalization by applying trade openness as the proxy of globalization (Acheampong et al., 2019; Kim et al., 2019; Shahbaz et al., 2017). Trade openness certainly affects CO_2 emissions. However, it cannot capture all the effects caused by globalization. Specifically, trade openness can represent the international trade, which is only one aspect of globalization, but it cannot represent other aspects of globalization, like the capital flows, information flows, political participation and so on. Thus, by using trade openness to study the impacts of globalization on carbon emissions, biased results could be obtained. In order to overcome this drawback, we apply the KOF globalization index[2] developed by Dreher (2006). This index divide globalization into three aspects, namely the economic globalization, social globalization and political globalization, and it is applied in some recent studies. You and Lv (2018) employed the economic globalization index to investigate its spatial effects on CO_2 emissions for 83 countries. Khan et al. (2019) used the KOF index to discover the influences of globalization, fossil energy consumption and other economic variables on CO_2 emissions for Pakistan. Other studies which used the KOF index can be found in Akadiri et al. (2019), Shujah Ur et al. (2019) and Zaidi et al. (2019).

Another disadvantage of previous literature is the regression methods that are applied when they attempted to research the impacts of globalization on carbon emissions. As shown in Appendix A, the common regression methods include dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), panel least squares (PLS), generalized method of moments (GMM), auto regressive distributed lag (ARDL) and so on. These methods belong to parametric estimation, whose assumptions about the regression models is strict. Whereas, the strict assumptions may result in specification errors. For example, the population is supposed to be normally distributed in the DOLS model. However, if the actual distribution of the population is not a normal distribution, the statistical inference provided by the DOLS model would deviate from the actual values. In order to avoid the possible specification errors, we applied a semi-parametric method proposed by Baltagi and Li (2002) in our paper. Abdallh and Abugamos (2017) also employed this method when they tried to explore the influences of urbanization on CO_2 emissions for 20 countries of the Middle East

[2] The KOF globalization index is constructed to measure globalization from economic, social and political dimensions, it contains 23 variables related to different aspects of globalization. Details of the variables and their weights are listed in Appendix B.

and North Africa. Similarly, Effiong (2018) applied the same method to investigate the impacts of urbanization on carbon emissions and PM_{10} emissions for 49 Africa countries. Moreover, parametric regression methods assume that determinant variables are linearly correlated to the dependent variable. Therefore, to check whether the Environmental Kuznets Curve (EKC) hypothesis[3] holds or not, the models in previous studies usually contains both the independent variables and the quadratic of the independent variables, see examples in Acheampong et al. (2019) and Zaidi et al. (2019). Unlike them, we can test whether the EKC hypothesis is valid by only investigating the shape of the relationship curve as the semi-parametric model does not assume a priori relationship between the dependent variable and determinant variables.

Based on the above motivations, we have two goals in this study. Firstly, we aim to provide flexible and comprehensive results about the influences of globalization on carbon emissions for the G7 countries. In addition, we also attempt to test the validity of the EKC hypothesis for globalization and carbon emissions. In order to accomplish this aim, we firstly introduce the KOF globalization index into traditional Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model. The KOF globalization index is a comprehensive index, it covers different aspects of globalization. Therefore, by applying the KOF globalization index, we could obtain more comprehensive results than previous studies. Secondly, we adopt a recent semi-parametric regression model to explore the influences of globalization on carbon emissions. In order to provide rigorous and robust results, we also apply parametric estimation methods as a comparative analysis. Moreover, renewable energy consumption and economic

[3] The EKC hypothesis refers to an assumption in which an inverted U-sharped relationship between CO_2 emissions and a determinant variable is proposed, especially the relationship between CO_2 emissions and economic growth.

growth which are two widely used variables in previous studies are also introduced as control variables in our paper.

The contribution of this study is twofold: firstly, a semi-parametric regression method is applied in this paper to investigate the impacts of globalization, renewable energy consumption and economic growth on CO_2 emissions for the G7 countries. Compared with the parametric regression method, the semi-parametric method can provide more flexible and comprehensive results about the impacts. Secondly, the results of this paper can help the G7 countries to formulate carbon reduction policies with respects to globalization, renewable energy and economic growth.

The structure of the remainder of this paper is listed as follows: Section 2 and 3 is about the regression methods and data applied in this paper. Section 4 analyzes the regression results and discusses the impacts of globalization on CO_2 emissions. Section 5 presents the conclusions and related policy proposals of this paper.

2. Methodology

2.1. Theoretical framework

Globalization is an important factor for CO_2 emissions, it makes countries interact with each other from economic, social and political aspects, and the interaction between different countries will inevitably affect the CO_2 emissions. The influences of globalization on carbon emissions were discussed in several published papers. However, their results are not consistent with respect to the impacts of globalization. Significantly negative influences are proved in these papers: Shujah Ur et al. (2019) reported that globalization significantly reduces CO_2 emission for the Central and Eastern European countries. You and Lv (2018) proved that the total effects of economic growth were negative and significant for 83 countries. Zaidi et al. (2019) reported that globalization has significantly negative influences on CO_2 emissions for the Asia Pacific Economic Cooperation countries. However, nonsignificant negative impacts are also observed in previous literature, like Akadiri et al. (2019) found that the influences of globalization are negative but not significant for Turkey. Nevertheless, significant positive effects are also provided in previous studies, like Khan et al. (2019) discovered that economic, social and political globalization have positive impacts on CO_2 emissions for Pakistan. With respect to the possible explanation of the effects of globalization, there are two kinds of explanation. The first explanation is the Pollution Haven Hypothesis. According to the Pollution Haven Hypothesis, the environmental protection regulations and laws are not well developed in the developing countries as the developing countries hope to achieve high-speed development, therefore, the industries related to heavy pollution move from developed countries to the developing countries. Another explanation is the Halo Effects Hypothesis. Based on the Halo Effects Hypothesis, the developing countries could reduce the carbon emissions as the carbon reduction technology would transfers from the developed countries to the developing countries.

Renewable energy consumption is also a decisive factor for carbon emissions. Although the application of renewable energy create CO_2 emissions, but far less than fossil energy do (Evans et al., 2009). Therefore, in order to control CO_2 emissions, renewable energy is widely used to substitute fossil energy in many countries. Previous literature also proved renewable energy is crucial for the reduction of CO_2 emissions (Acheampong et al., 2019; Cheng et al., 2019).

Economic growth is another determinant factor for CO_2 emissions. The most classical theory which depicts the connection between economic growth and carbon emissions is the EKC hypothesis, in which an inverted U-sharped curve is used to describe the relationship. Overall, previous studies about the influences of economic growth on CO_2 emissions failed to reach a consensus. Some scholars claimed that the EKC hypothesis is valid (Zhang and Zhang, 2018), but some scholars proved that the EKC hypothesis is invalid (Acheampong et al., 2019), even some scholars provide N-sharped relationship for the economic growth and carbon emissions (Balsalobre-Lorente et al., 2018).

In order to discover the influences of globalization, renewable energy consumption and economic growth on CO_2 emissions for G7 countries, we apply the STIRPAT model put forward by Dietz and Rosa (1997). Other scholars also tend to apply the STIRPAT model when they attempt to investigate the decisive factors of carbon emissions, see other examples in Abdallh and Abugamos (2017) and Zafar et al. (2019). The traditional STIRPAT model is presented below:

$$CE_{i,t} = f\left(P_{i,t}, A_{i,t}, T_{i,t}\right) = \alpha_i P_{i,t}^{\beta_1} A_{i,t}^{\beta_2} T_{i,t}^{\beta_3} e_{i,t}$$

where $CE_{i,t}$ denotes CO_2 emission of countries i at time t, $P_{i,t}$ refers to the population of countries i at time t, $A_{i,t}^{\beta_2}$ represents to the affluence of countries i at time t, $T_{i,t}^{\beta_3}$ refers to the technology of countries i at time t, α_i, β_1, β_2 and β_3 represent the estimated coefficients of the STIRPAT model. $e_{i,t}$ refers to the random stochastic error.

In order to discover the impacts of other determinate variables on CO_2 emissions, several other variables are incorporated into the STIRPAT model, such as renewable energy, urbanization, energy intensity (Abdallh and Abugamos, 2017; Zafar et al., 2019). Therefore, following them, this study extends the traditional STIRPAT model by taking globalization and renewable energy consumption into consideration. Consequently, the extended STIRPAT model applied in our study is given by:

$$CE_{i,t} = \alpha_i GDP_{i,t}^{\beta_1} RE_{i,t}^{\beta_2} KOFGI_{i,t}^{\beta_3} e_{i,t}$$

where GDP denotes economic growth, RE represents renewable energy consumption and $KOFGI$ refers to KOF globalization index.

After taking the natural logarithm of the extended STIRPAT model, Eq. (1) can be converted to the linear logarithmic form as follows:

$$\ln CE_{i,t} = \beta_1(\ln GDP_{i,t}) + \beta_2(\ln RE_{i,t}) + \beta_3(\ln KOFGI_{i,t}) + \alpha_i + e_{i,t} \qquad (1)$$

where $CE_{i,t}$ denotes the total CO_2 emissions of country i in year t. $GDP_{i,t}$, $RE_{i,t}$ and $KOFGI_{i,t}$ represent GDP per capita, renewable energy consumption per capita and globalization of country i in year t, respectively. α_i is the fixed effects parameter, t indicates the time span (which is 1970-2015 in this study), and i stands for countries (from 1 to 7).

2.2. Econometric methods

As there exists a prior assumption about the possible relationship between determinant variables and dependent variables in the parametric regression methods, parametric regression methods may cause model misspecification (Hsiao, 2007). To avoid this kind of misspecification and to obtain accurate inference of model parameters, we apply a semi-parametric panel data method with fixed effects (SPMFE) developed by Baltagi and Li (2002) to explore the influences of globalization, renewable energy consumption and economic growth on CO_2 emissions. Moreover, we also aim to check the validity of the EKC hypothesis for globalization and carbon emissions. Compared with the parametric method, the semi-parametric method is more flexible as it would not assume a priori relationship between globalization and carbon emissions. To be specific, the SPMFE model in our paper is given by:

$$\ln CE_{i,t} = \beta_1\left(\ln GDP_{i,t}\right) + \beta_2\left(\ln RE_{i,t}\right) + g\left(\ln KOFGI_{i,t}\right) + \alpha_i + e_{i,t} \qquad (2)$$

where the functional form of $g(.)$ is undetermined and unspecified. In this model, if the EKC hypothesis for globalization and CO_2 emissions holds, the coefficient $g(.)$ will form an inverted-U curve. To exclude the fixed effects α_i, a common procedure is to differentiate (2) over time, which leads to

$$\ln CE_{i,t} - \ln CE_{i,t-1} = \beta_1\left(\ln GDP_{i,t} - \ln GDP_{i,t-1}\right) + \beta_2\left(\ln RE_{i,t} - \ln RE_{i,t-1}\right) +$$

$$\left\{g\left(\ln KOFGI_{i,t}\right) - g\left(\ln KOFGI_{i,t-1}\right)\right\} + e_{i,t} - e_{i,t-1} \qquad (3)$$

In order to gauge the unknown function of $\left\{g\left(\ln KOFGI_{i,t}\right) - g\left(\ln KOFGI_{i,t-1}\right)\right\}$, we follow Baltagi and Li (2002) and use a spline series $p^k(\ln KOFGI_{i,t})$ to approximately estimate $g\left(\ln KOFGI_{i,t}\right)$, where $p^k\left(\ln KOFGI_{i,t}\right)$ is the first k terms of a sequence of functions $(p_1\left(\ln KOFGI_{i,t}\right),\ p_2\left(\ln KOFGI_{i,t}\right),\ \ldots)$. Then $g\left(\ln KOFGI_{i,t}\right) - g\left(\ln KOFGI_{i,t-1}\right)$ can be estimate by the series differences $p^k\left(\ln KOFGI_{i,t}\right) - p^k(\ln KOFGI_{i,t-1})$. In this research, following Newson (2001) and Desbordes and Verardi (2012), we use a B-spline regression model with $k = 4$.

Moreover, to compare the results of the parametric panel method with fixed effects (PMFE) and semi-parametric panel method with fixed effects, we also apply two traditional panel regression model with fixed effects. The parametric regression models are given by:

$$\ln CE_{i,t} = \beta_1\left(\ln GDP_{i,t}\right) + \beta_2\left(\ln RE_{i,t}\right) + \beta_3\left(\ln KOFGI_{i,t}\right) + \alpha_i + e_{i,t} \qquad (5)$$

$$\ln CE_{i,t} = \beta_1\left(\ln GDP_{i,t}\right) + \beta_2\left(\ln RE_{i,t}\right) + \beta_3\left(\ln KOFGI_{i,t}\right) + \beta_4\left(\ln KOFGI_{i,t}^2\right) + \alpha_i + e_{i,t}$$

(6)

3. Data

To explore the effects of globalization, renewable energy consumption and economic growth on carbon emissions, we use a balanced panel data of G7 countries which covers the time span of 1970-2015. In our case, the variables consist of CO_2 emissions per capita (denoted as CE), GDP per capita (denoted as GDP), renewable energy consumption per capita (denoted as RE), and KOF Globalization Index (denoted as $KOFGI$). The KOF Globalization index is collected from the Swiss Federal Institute of Technology (Dreher, 2006), the data of other variables are collected from the World Bank database. Table 1 displays the basic statistics of the four variables of our data. Specifically, it contains the standard deviation and the mean, minimum and maximum values of four variables in this study.

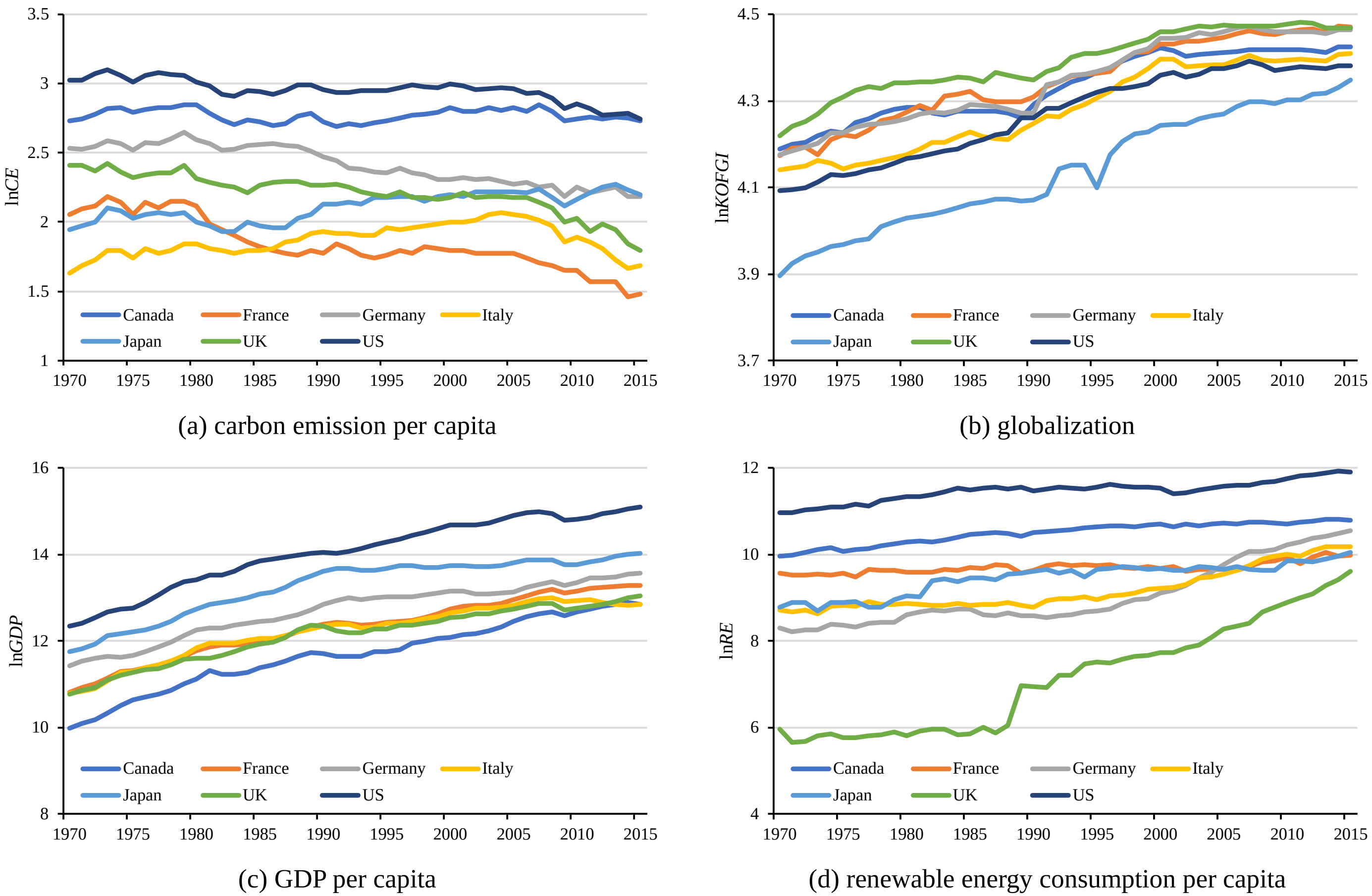
Table 1. Descriptive statistics of the selected variables (after logarithm).

Variable	Definition	Mean	Std. Dev.	Min	Max
CE	CO_2 emissions, kg CO_2 per capita	2.31	0.42	1.46	3.10
GDP	GDP per capita, constant 2010 US dollars	12.62	1.02	9.97	15.09
RE	Gross inland renewable energy consumption, tonnes oil equivalent per capita	-1.73	1.30	-5.27	0.37
$KOFGI$	KOF Globalization index, unitless variable	4.30	0.13	3.90	4.48

Note: Std. Dev denotes standard deviation.

The trends of the four variables are displayed in Fig. 1. As shown in Fig. 1a, although the

CO_2 emissions per capita fluctuated during 1970-2015 in the G7 countries, it kept decreasing in the long term. Regarding the KOF globalization index, it kept increasing in a fluctuant way, details can be observed in Fig. 1b. The ever-increasing KOF globalization index implies that the G7 countries actively participate in the globalization process from economic, social and political aspects. With respect to the GDP per capita, it kept increasing in this period in the G7 countries (see Fig. 1c), indicating that the economy in the G7 countries kept increasing. Similarly, as shown in Fig. 1d, renewable energy consumption per capita also kept increasing in the long-run. As the KOF globalization index, the GDP per capita, and the renewable energy consumption per capita increased when the CO_2 emissions per capita decreased in the G7 countries, so it is interesting to explore the different effects of globalization, economic growth and renewable energy consumption on the reduction of CO_2 emissions in the G7 countries.



(a) carbon emission per capita

(b) globalization

(c) GDP per capita

(d) renewable energy consumption per capita

Fig. 1. The trends of CE, KOFGI, GDP and RE in the G7 countries during 1970-2015 (after logarithm).

4. Empirical analysis and discussions

4.1. Panel unit root tests and cointegration tests

Before we proceed to conduct the rigorous empirical investigation with the SPMFE model and the PMFE model, we conduct unit root tests for the four variables to check whether these four chosen variables are stationary or not. Specifically, both first generation and second generation panel unit root tests are applied in our paper. The test results are displayed in Table 2. As we can see, the results imply that carbon emissions, GDP, renewable energy consumption and KOF globalization index are non-stationary at levels as most of the results are not significant for the four variables at levels. Meanwhile, all the test methods indicate that the first difference of these four variables is stationary. Therefore, in the later analysis, we use the first difference when conducting the regression process. Consequently, the regression results imply the elasticity of the independent factors on carbon emissions.

After conducting the panel unit root tests, we continue to conduct the panel cointegration tests to examine whether the variables share a common long-term relationship. Specifically, we apply seven kinds of panel cointegration test methods proposed by Pedroni (1999). The results are displayed in Table 3. As mentioned by Pedroni (1999), the null hypothesis of the cointegration tests is that the variables are no cointegration in the long-term. Based on the results, the null hypothesis is rejected at the 1% significance level in the seven tests. These results confirm that there are long-term cointegrating relationships among carbon emissions and the three independent variables within our sample data.

Table 2. Panel unit root tests.

Variable	IPS	Fisher-ADF	Fisher-PP	CIPS
CE	2.10	-1.39	-0.83	-2.24
GDP	1.17	-1.28	-1.20	-2.57
RE	2.07	-1.87	-0.48	-1.80
$KOFGI$	1.97	-1.62	-1.12	-2.85*
First difference				
CE	-4.32***	48.79***	231.47***	-5.96***
GDP	-5.24***	58.46***	84.14***	-4.40***
RE	-3.87***	48.35***	297.57***	-5.13***
$KOFGI$	-2.76***	31.04***	207.14***	-6.02***

Note: This table presents the results of four panel unit root tests for all variables. The estimation is performed with the intercept and trend terms.

*, ** and *** indicate the significance levels at the 10%, 5% and 1%, respectively.

Table 3. Panel Cointegration tests.

Variable	Empirical value	Standardized value	p-value
Panel υ-Statistic	0.03	-3.26***	0.0020
Panel ρ-Statistic	-15.37	2.95***	0.0052
Panel *t*-Statistic (non-parametric)	-4.09	3.79***	0.0003
Panel *t*-Statistic (parametric)	-3925.80	-4067.22***	0.0000
Group ρ-Statistic	-19.62	4.04***	0.0001
Group *t*-Statistic (non-parametric)	-4.38	5.29***	0.0000

Group *t*-Statistic (parametric)	-4.31	5.38***	0.0000

Note: This table displays seven panel cointegration tests in Pedroni (1999). The standardized values of the test statistics are asymptotically normal (0, 1) under the null hypothesis.

*, ** and *** indicate the rejection of the null hypothesis at the 10%, 5% and 1% significance levels, respectively.

4.2. Results of the SPMFE model and PMFE model

In order to assure that the fixed effects model is fit for our sample, we apply the Hausman test to examine whether the panel fixed effects model is an appropriate specification. The null hypothesis of the Hausman test is that panel random effects model suit for the data. The Hausman test of our sample data, whose p value equals to 0.0456, indicates that the null hypothesis should be rejected. Therefore, after taking the Hausman test, we could confirm that the panel fixed effects model is the appropriate model for the sample data. Therefore, we empirically examine the impacts of economic growth, renewable energy consumption and globalization on CO_2 emissions in G7 countries by using both the SPMFE model and PMFE model.

The results of the PMFE model are displayed in Table 4. Table 4 also presents the results of the control variables (i.e. RE and GDP) estimated by the SPMFE model. Column 1 describes the estimation results provided by the PMFE model without considering EKC (namely the Equation 5), while Column 2 shows the estimated results of the PMFE model with EKC (i.e. the Equation 6). In addition, Column 3 of Table 4 presents the results for renewable energy consumption and economic growth estimated by the SPMFE model. The results of the relationship between globalization and carbon emissions are shown in Fig. 2. Based on the results, several conclusions can be drawn.

1) Renewable energy is vital for the decrease in carbon emissions for the G7 countries.

As shown in Table 4, the elasticities of carbon emissions with respect to renewable energy consumption are significantly negative for the three regression models, indicating that renewable energy consumption exerts negative impacts on carbon emissions. Similar results are also provided by Zafar et al. (2019) who also demonstrated that renewable energy has negative influences on carbon emissions in the G7 countries. Renewable energy belongs to clean energy, its life-cycle CO_2 emissions is much less than that of fossil energy (Evans et al., 2009). Therefore, the application of renewable energy contributes to the reduction of carbon emissions.

2) Inconsistent impacts of economic growth on carbon emissions are observed in three regression methods for the G7 countries.

As shown in Table 4, the elasticity of carbon emission regarding economic growth is inconsistent in the 3 models. Specifically, the elasticity is positive but insignificant in the PMFE model without considering the EKC hypothesis, while it is negative and insignificant in the PMFE model considering the EKC hypothesis. Moreover, the elasticity is positive and significant in the SPMFE model. According to the significantly positive influences provided by the SPMFE model, we conclude that economic growth could lead to more carbon emissions for the G7 countries, which is also observed in other studies related to G7 countries (Awaworyi Churchill et al., 2019; Zafar et al., 2019).

One possible explanation of the positive impacts of economic growth on carbon emissions is the energy consumption and its structure of the G7 countries. Energy is an important pillar of economic growth (Belke et al., 2011; Shujah Ur et al., 2019). In order to maintain economic growth, more energy is needed. In term of the G7 countries, most of them maintained steady economic growth in recent years. Consequently, the energy consumption of the G7 countries kept increasing in recent years (BP, 2018). However, although renewable energy has developed rapidly in the G7 countries, most of the energy consumption is provided by fossil energy (BP, 2018). Taking 2018 as an example, the ratio of renewable energy consumption to the gross energy consumption was only approximate 5.9% in the G7 countries, while fossil energy consumption made up 51.9% of the total energy consumption. Moreover, compared with renewable energy, fossil energy emits more CO_2. Therefore, an increase in economic growth could lead to an increment of CO_2 emission in the G7 countries.

3) Inverted-U curve relationship exists between globalization and carbon emissions.

Fig. 2 shows the results of estimated by the SPMFE model. $g(\cdot)$ is an undetermined coefficient which describes the connection between $KOFGI$ and CO_2 emissions. As shown in Fig. 2, we conclude that the connection between globalization and carbon emissions exhibits an inverted-U curve. This conclusion is in favor of the validity of the EKC hypothesis between globalization and carbon emissions. In other words, the growth of globalization firstly exerts a considerable positive influence on carbon emissions. Then, when the globalization level exceeds a certain extent, the effects of the increase of globalization on the carbon emissions change into negative.

4) Parametric regression model underestimates the impacts of the determinate variables.

As shown in Table 4, the coefficients (absolute value) obtained by PMFE model without the EKC hypothesis and PMFE model with the EKC hypothesis are smaller than the counterparts provided by the SPMFE model. To be specific, although the results of the SPMFE prove that the GDP growth plays an essential role in increasing the level of carbon emissions. However, the coefficients of GDP in the two parametric panel data models are not statistically significant. In terms of RE, a similar rule can be observed. The coefficients of RE which are provided by the parametric panel data models are -0.03 and -0.04 respectively. In contrast, the corresponding estimated coefficient in the semi-parametric panel model is -0.05, which present the parametric estimation underestimate the impacts of RE compared with the semi-parametric estimation. Therefore, we conclude that the coefficients (absolute value) may be underestimated in the absence of the nonlinear relationship between globalization and carbon emissions. Moreover, this kind of underestimation bias about the impacts of driven factors can be mitigated by applying the semi-parametric panel model.

Table 4. Main results of the PMFE model and SPMFE model.

Variables	**PMFE (1）**		**PMFE (2)**		**SPMFE**	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
GDP	0.06	0.0612	-0.09	0.0514	0.10**	0.0413
RE	-0.03*	0.0171	-0.04***	0.0139	-0.05***	0.0181
$KOFGI$	1.56***	0.3026	38.55***	3.1496		
$KOFGI^2$			-4.65***	0.3950		
Country dummies	Yes		Yes		Yes	
Year dummies	Yes		Yes		Yes	

Note: This table shows the results of the PMFE model and SPMFE model.

*, ** and *** indicate the significance levels at the 10%, 5% and 1%, respectively.

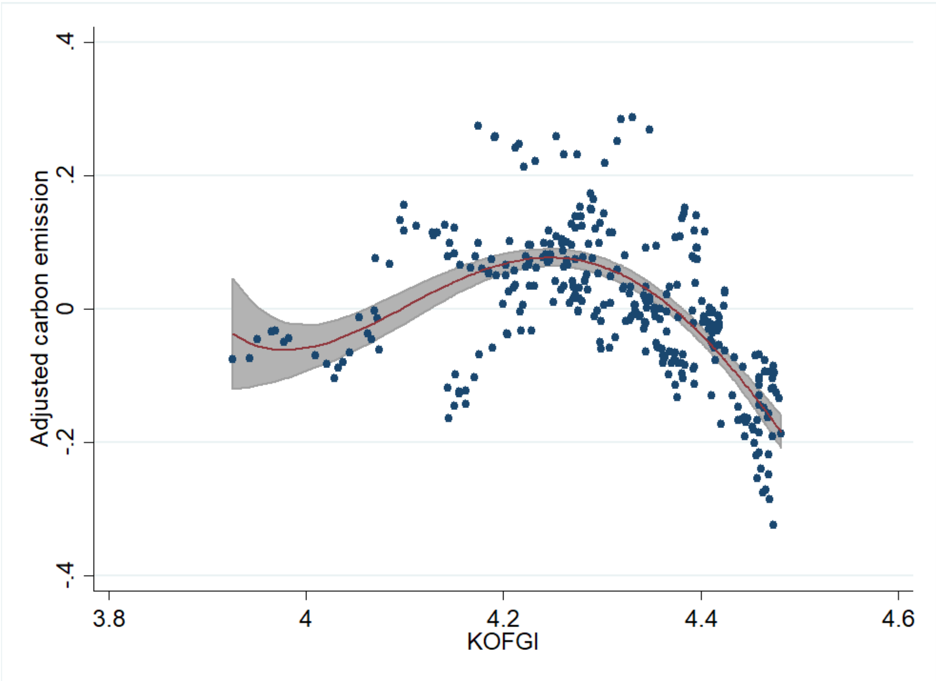


Fig. 2. Partial fitness of the functional form for $g(\cdot)$.

Note: The points centered on the mean are the partial residuals for CO_2 emissions in the semi-parametric model. The maroon curve with shaded areas denotes estimation of $g(\cdot)$ with 95% confidence intervals provided by the semi-parametric model.

4.3. Discussions about the EKC hypothesis between globalization and carbon emissions

Possible explanations of the inverted U-sharped relationship between globalization and CO_2 emissions are complicated. As mentioned above, the KOF globalization index includes economic globalization, social globalization and political globalization. Consequently, we will discuss the causes of the EKC hypothesis from these three aspects. When we attempt to explain the impacts of globalization from one aspect (take economic aspects for example), we just focus on the impacts of economic globalization, and neglect the impacts of social and pollical impacts of globalization. The detailed discussion is shown below:

In terms of economic globalization, the EKC hypothesis could be interpreted by the Pollution Haven Hypothesis. Specifically, in the early stage of globalization, although the G7 countries belonged to developed countries, the rest countries in the world were much less developed than the G7 countries. Therefore, the G7 countries still served as important producers and exporters in goods and service. Later on, along with the development of globalization, many developing countries started to their own industrialization while the developed countries began to migrate their pollution-intensive industry via globalization (Cole, 2004; Kolcava et al., 2019). In order to gain more profits from globalization and international trade, some developing countries did not pay too much attention to environmental issues, and developed the pollution-intensive industry which was transferred by the developed countries. This phenomenon is called as Pollution Haven Hypothesis. Moreover, the Pollution Haven Hypothesis is also verified by the data obtained from the world bank database: Firstly, the value added by the industry which is the main CO_2 emission source of one country kept decreasing since 1970. Secondly, the total net trade in goods and service of the G7 countries kept negative since 1999, and most of the G7 countries were net importer since 2005. These indicate that the G7 countries gradually relocate their pollution-intensive industry, and switched their role from world factory to net imports of goods and service. In a word, the Pollution Haven Hypothesis is the possible explanations for the EKC hypothesis of globalization from the economic perspective.

With respect to social globalization, the EKC hypothesis could be explained in this way: In the initial stage of globalization, the living quality of the residents started to improve, such as people start to travel abroad, or get connected with foreign friends via telephone or internet. Consequently, the CO_2 emissions per capita started to grow, causing the total CO_2 emissions of the country to increase. However, with the deeper development of globalization, environmental awareness is widely spread across the world via cultural exchange, tourism, internet and other ways. Moreover, the generation and promotion of environmental awareness are beneficial to the reduction of CO_2 emissions (Chen et al., 2019). This is also partial confirmed by the data from world bank database: Firstly, the net transfers income from abroad of the G7 countries kept positive from 1981, and most of the G7 countries obtain positive net transfers since 2001. This indicates that plenty of people from the G7 countries work aboard, and spread their culture and environmental awareness. Secondly, internet users and international travellers also kept increasing in recent years, meanwhile, the internet and tourism are powerful tools for the cultural exchange and spread of environmental awareness. In brief, the cultural exchange and environmental awareness are the possible explanations for the EKC hypothesis of globalization from the social perspective.

With regards to political globalization, the possible interpretation could be in this way: In the early stage of globalization, there were few international agencies or organizations which cared about the environmental issues. However, as much attention has been attached to the damage caused by excessive CO_2 emissions, several international agencies and organizations have been established, such as the Global Environment Facility. Apart from the establishment of these organizations, more and more countries started to participate in global environmental protection due to the development of political globalization. Consequently, the CO_2 emissions would decrease along with the promotion of political globalization. This could be partially verified by the active participation of the G7 countries (apart from the United States) in the Paris Climate Agreement. In short, the establishment and participation in global environmental agencies are the main reasons for the reduction of carbon emissions in the G7 countries from the political perspective.

In summary, the explanations of the EKC hypothesis between globalization and CO_2 emissions are displayed in Fig. 3.

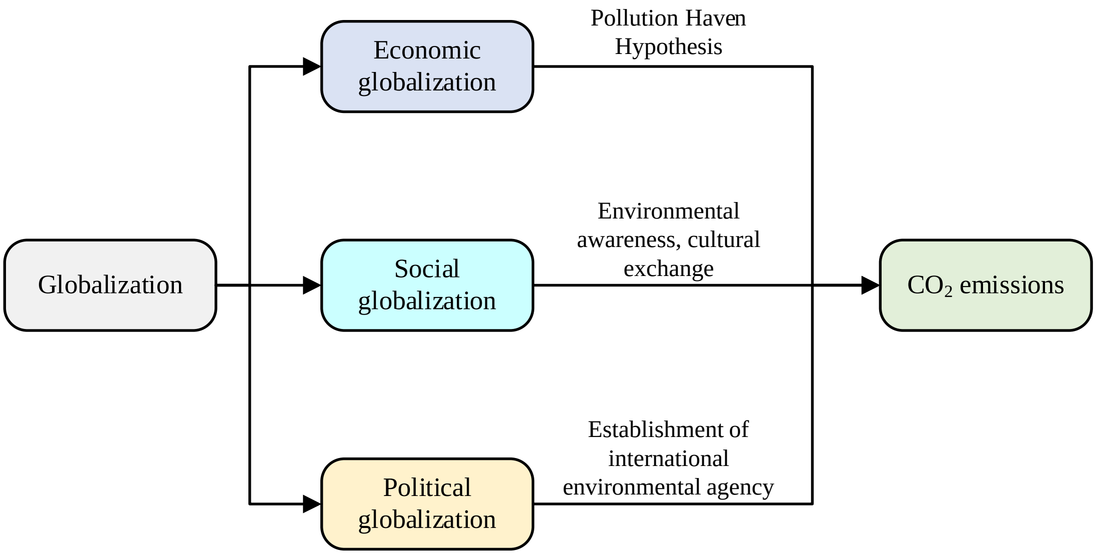


Fig. 3. Impacts of globalization on CO_2 emissions from three aspects.

4.4. Robust analysis

In addition, a lot of previous studies have examined the validity of the inverted-U relationship between GDP and carbon emission. Here, we consider the following model as a robust check.

$$\ln CE_{i,t} = \beta_1(\ln KOFGI_{i,t}) + \beta_2(\ln RE_{i,t}) + g(\ln GDP_{i,t}) + \alpha_i + e_{i,t} \qquad (7)$$

In model (7), in order to verify the possible nonlinear relationship, the nonparametric variable is changed from $KOFGI$ into GDP. The results of the robust check are presented in Table 5 and Fig. 4. Clearly, as shown in Fig. 4, we can observe that GDP is linearly correlated to CO_2 emissions, which implies that there is no inverted-U relationship between GDP and carbon emission. In other words, our results do not support the EKC hypothesis between GDP and carbon emission. Moreover, from a statistical perspective, the coefficients of $KOFGI$ are not significant in both linear and quadratic terms. This further illustrates that even though the linear or quadratic terms of globalization can be taken into consideration when estimating the coefficients, traditional parametric panel data models could not accurately depict the relationship between globalization and carbon emission. In sum, the semi-parametric model can help us comprehensively understand the relationship between determinant factors and CO_2 emissions in G7 countries.

Table 5. Robust check: Nonparametric variable = GDP.

Variables	**SPMFE (1)**		**SPMFE (2)**	
	Coefficient	Std. Error	Coefficient	Std. Error
RE	-0.05***	0.0184	-0.05***	0.0183
$KOFGI$	-0.25	0.1732	8.59	5.4434
$KOFGI^2$			-1.05	0.6457
Country dummies	Yes		Yes	
Year dummies	Yes		Yes	

Note: This table shows the results of the SPMFE model with Nonparametric variable = GDP.

*, ** and *** indicate the significance levels at the 10%, 5% and 1%, respectively.

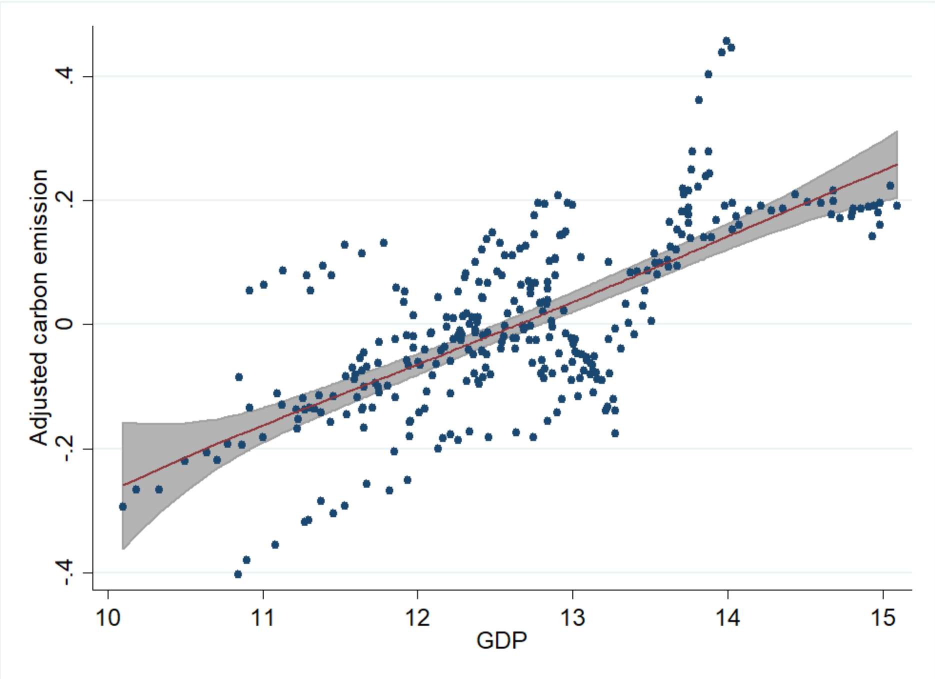


Fig. 4. Partial fitness of the functional form for $g(\cdot)$ (Nonparametric variable = GDP in the semi-parametric model).

Note: The points centered on the mean are the partial residuals for CO_2 emissions in the semi-parametric model. The maroon curve with shaded areas denotes estimation of $g(\cdot)$ with 95% confidence intervals provided by the semi-parametric model.

5. Conclusions and policy implications

5.1. Main conclusions

To flexibly and comprehensively explore the effects of globalization, renewable energy and economic growth on carbon emissions for the G7 countries, this paper employs both parametric panel fixed effects model and semi-parametric panel fixed effects model. The data consist of CO_2 emissions per capita, KOF globalization index, renewable energy consumption per capita and GDP per capita, and the time span is 1970-2015. Moreover, the existence of the EKC hypothesis between globalization and carbon emissions are also checked by different models. Based on the regression results, we conclude that: 1) Inverted U-sharped relationship exists between globalization and carbon emissions, possible explanations include Pollution Haven Hypothesis, cultural exchange, environmental awareness and establishment of international environmental agencies; 2) Development of renewable energy is a crucial approach to the reduction of the carbon emissions for the G7 countries; 3) Inconsistent impacts of economic growth on CO_2 emissions are observed in the three regression methods for the G7 countries, but overall, economic growth exerts a positive influence on carbon emission; 4) Parametric regression model underestimates the impacts of the determinate variables.

5.2. Policy implications

Based on the conclusions we obtain, we propose the related policy recommendations as follows:

1) Renewable energy should be given priority in the energy consumption structure. As renewable energy benefit for the mitigation of carbon emissions, therefore, the government need to facilitate the development of renewable energy to achieve sustainable development. Such policies may include providing feed-in tariff and renewable energy certificate for the electricity generated by renewable energy. Moreover, the government should provide more R&D expenditure on the cost reduction to cut down the generation costs of renewable energy. The improvement of technology would facilitate the process of grid parity, which in return

relieve the financial burdens of the government.

2) The green economy should be laid more attention in order to achieve sustainable development. Although economic growth could aggravate global warming by emitting more CO_2, its negative impacts on the environment issues could be partly mitigated by the green economy. Based on the concept of the green economy, the government should find a balance between economic growth and environmental protection. Consequently, on one hand, the government should modify the structure of energy consumption; moreover, the government should encourage the transfers of technology to improve the energy efficiency and energy conservation, similar policy recommendation can be found in Yan et al. (2019).

3) Countries should participate in the globalization process. As there exists an inverted-U relationship between globalization and carbon emissions, therefore, all the countries should take part in the globalization process as the high level of globalization is beneficial for the mitigation of carbon emissions.

4) Technology barriers which hinder the transfers of sophisticated technology should be removed. In order to conquer the drawbacks of the economic globalization (namely the Pollution Haven Hypothesis), technologies, especially those are related to CO_2 reduction should be encouraged to be applied and transferred across the world. According to the Halo Effects Hypothesis, the CO_2 emission of the world would decrease, rather than transfer from one country to another by the spread of CO_2 reduction technology. The Halo Effects Hypothesis conjectures that with the help of international trade, transnational operation of international corporations and technology transfer, the level of environmental protection of the host country would be improved. Consequently, the CO_2 emissions of the host country would decrease. The

Halo Effects Hypothesis was confirmed by Atici (2012) and Zhu et al. (2016). Therefore, technology transfer barriers, especially those are related to CO_2 reduction should be removed in order to mitigate the problems caused by CO_2 emissions and improve global environmental quality.

5.3. Limitations and future research directions

The limitation of this paper is that only the G7 countries are considered in this paper, therefore, some conclusions may not be suitable for other countries. Therefore, in the future, we would apply the semi-parametric regression method to investigate the impacts of globalization on CO_2 emissions in a broader sample which not only include the developed countries, but also covers the developing countries.

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Appendix A Selective literature related to CO_2 emissions and its decisive factors.

No.	Authors	Countries or areas	Decisive factors	Regression methodology
1	Abdallh and Abugamos (2017)	20 MENA countries	1, 4, 5, 6	Semi-parametric panel regression
2	Acheampong (2018)	116 countries	1, 7, 8	PVAR, System-GMM
3	Acheampong et al. (2019)	46 Sub-Saharan African countries	1, 2, 5, 8, 9, 10, 11, 12	Instrumental variable GMM
4	Adams and Acheampong (2019)	46 Sub-Saharan African countries	1, 2, 5, 8, 9, 10, 13, 14	Instrumental variable GMM
5	Adams and Nsiah (2019)	28 Sub-Sahara African countries	1, 9, 15, 16, 17, 18, 19, 21	FMOLS and GMM
6	Akalpler and Hove (2019)	India	1, 7, 22, 23	ARDL
7	Akadiri et al. (2019)	Turkey	1, 24, 25	FMOLS and panel VECM
8	Balsalobre-Lorente et al. (2018)	EU-5 countries	1, 2, 3, 8, 9, 26, 27	PLS
9	Awaworyi Churchill et al. (2019)	G-7 countries	1, 2, 5, 8, 28, 29	Non-parametric panel regression
10	Hanif et al. (2019)	25 Asian countries	1, 2, 5, 9, 30, 31	Two-step system GMM

11	Khan et al. (2019)	Pakistan	1, 8, 10, 11, 30, 32, 33, 34, 35, 36	Dynamic ARDL
12	Kim et al. (2019)	131 countries	1, 2, 6, 18, 37, 38, 39, 40, 41, 42, 43	Quantile regression
13	Li et al. (2019)	30 Chinese provinces	6, 44, 45, 46, 47	PLS
14	Liu et al. (2019)	50 US states and the District of Columbia	1, 7, 48,49	ARDL, quantile regression
15	Rahman and Kashem (2017)	Bangladesh	1, 50	ARDL
16	Dehghan Shabani and Shahnazi (2019)	Iran	1, 2, 7, 51	DOLS
17	Shahbaz et al. (2017)	105 countries	1, 8	FMOLS and panel VECM
18	Shujah Ur et al. (2019)	16 Central and Eastern European countries	1, 2, 7, 9, 11, 24	DSUR
19	Zafar et al. (2019)	G-7 countries & N-11 countries	1, 2, 9, 22, 52, 53	CUP-BC, CUP-FM
20	You and Lv (2018)	83 countries	1, 5, 19, 24, 49	Spatial dubin model
21	Zaidi et al. (2019)	17 APEC countries	1, 2, 4, 11, 24	CUP-BC, CUP-FM
22	Zhang et al. (2017)	141 countries	1, 5, 8, 19, 20, 54, 55, 56, 57	Two-way fixed effects model
23	Zhang and Zhang (2018)	China	1, 2, 10, 58, 59	Error correction model

24	Zhou et al. (2019)	16 cities around the Yangtze River Delta	1, 4, 10, 18, 19, 28, 49, 60, 61, 62, 63, 64, 65	Stepwise panel regression

Notes: 1) decisive factors: 1 denotes GDP, 2 represents GDP^2, 3 refers to GDP^3, 4 denotes energy intensity, 5 represents total population, 6 refers to urbanization, 7 denotes energy consumption per capita, 8 represents trade openness, 9 refers to renewable energy consumption, 10 denotes foreign direct investment, 11 represents financial development, 12 refers to government regulations, 13 denotes to total urban population, 14 represents democracy, 15 refers to capital stock, 16 denotes quantity of labor force, 17 represents non-renewable energy consumption, 18 refers to population density, 19 denotes proportion of urban population, 20 represents the square of proportion of urban population, 21 refers to regime type, 22 denotes gross fixed capital formation per capita, 23 represents exports per capita, 24 refers to globalization, 25 denotes international tourists' arrivals, 26 represents abundance of natural resources, 27 refers to energy innovation, 28 denotes research & development, 29 represents broad money, 30 refers to fossil energy consumption, 31 denotes natural resources depletion, 32 represents urban population growth, 33 refers to innovations, 34 denotes social globalization index, 35 represents political globalization index, 36 refers to economic globalization index, 37 denotes trade with advanced countries, 38 represents trade with developing countries, 39 refers to imports from advanced countries, 40 denotes imports from developing countries, 41 represents exports to advanced countries, 42 refers to exports to developing countries, 43 denotes the year of schooling, 44 represents industrialization, 45 refers to agricultural modernization, 46 denotes informatization, 47 represents ecological modernization, 48 refers to income share of the top 10%, 49 denotes industry structure, 50 represents industrial production quantum index per capita, 51 refers to information and communication technology per capita, 52 denotes bank development index, 53 represents stock market development index, 54 refers to popular structure, 55 denotes GDP growth, 56 represents urban agglomeration, 57 refers urban primacy, 58 denotes trade structure, 59 represents exchange rate, 60 refers to fixed assets investment, 61 denotes proportion of urban area, 62 represents social consumption level, 63 refers to proportion of university student, 64 denotes civil vehicle ownership, 65 represents highway mileage.

2) methodology: PVAR denotes panel vector autoregression, System-GMM represents system-generalized method of moment, ARDL refers to auto regressive distributed lag, PLS denotes panel least squares, DOLS represents dynamic ordinary least squares, FMOLS refers to fully modified ordinary least squares, VECM denotes vector error correction model, DSUR represents dynamic seemingly unrelated cointegrating regression, CUP-BC refers to continuously updated bias-corrected, CUP-FM denotes to continuously updated fully modified.

Appendix B KOF Globalization index.

Indices and variables	
1. Economic globalization	
	1.1.1. Trade (percentage of GDP)
	1.1.2. Foreign direct investment, flows (percentage of GDP)
1.1. Actual flows	1.1.3. Foreign direct investment, stocks (percentage of GDP)
	1.1.4. Portfolio investment (percentage of GDP)
	1.1.5. Income payments to foreign nationals (percentage of GDP)
	1.2.1. Hidden import barriers
	1.2.2. Mean tariff rate
1.2. Restrictions	1.2.3. Taxes on international trade (percentage of current revenue)
	1.2.4. Capital account restrictions
2. Social globalization	
	2.1.1. Outgoing telephone traffic
	2.2.2. Transfers (percentage of GDP)
2.1. Data on personal contact	2.2.3. International tourism
	2.2.4. Foreign population (percentage of total population)
	2.2.5. International letters (per capita)
	2.2.1. Internet hosts (per 1,000 people)
2.2. Data on information flows	2.2.2. Internet users (per 1,000 people)
	2.2.3. Cable television (per 1,000 people)

	2.2.4. Trade in newspapers (percentage of GDP)
	2.2.5. Radios (per 1,000 people)
2.3. Data on cultural proximity	2.3.1. Number of McDonald's Restaurants (per capita)
	2.3.2. Number of Ikea (per capita)
	2.3.3. Trade in books (percentage of GDP)
3. political globalization	
	3.1.1. Embassies in country
	3.1.2. Membership in international organizations
	3.1.3. Participation in U.N. Security Council missions

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