The impacts of globalization, financial development, government expenditures, and institutional quality on CO$_2$ emissions in the presence of environmental Kuznets curve

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Received: 4 March 2020 / Accepted: 7 April 2020 / Published online: 22 April 2020
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Abstract
The main objective of this study is to examine the impacts of globalization, financial development, government expenditures, and institutional quality on CO$_2$ emissions, incorporating energy consumption, and GDP per capita in the Environmental Kuznets Curve (EKC) model for 47 Emerging Market and Developing Economies (EMDEs) between 1990 and 2014. Owing to the presence of cross-sectional dependence and slope heterogeneity in the panel data, CADF and CIPS unit root tests are employed to validate the stationarity of the variables. Westerlund (Oxf Bull Econ Stat 69:709–748, 2007) and Banerjee and Carrion-i-Silvestre (J Time Ser Anal 38:610–636, 2017) cointegration tests denote the occurrence of cointegration among the variables. We employed CCEMG, AMG, and DCCE estimators to estimate heterogeneous parameters. The findings demonstrate that globalization, financial development, and energy consumption increase CO$_2$ emissions. Besides, the EKC hypothesis is affirmed in EMDEs. The accrual of government's financial and governance activities also boosts carbon dioxide emissions. Moreover, the analysis of Dumitrescu and Hurlin causality provides evidences for the feedbacks among the variables and CO$_2$ emissions. From the aforementioned results, there exists the trade-off effect between economic growth and environmental quality in EMDE countries. Finally, the empirical findings of this study indicate profound implications for policy makers, which recommend governments to consider the role of finance and governance in order to ensure that energy consumption, financial development, and sustainable economic growth are in harmony with the environment in the globalization era.

Keywords Globalization · Financial development · Government expenditures · Institutional quality · Environmental degradation

Introduction
In recent years, environmental degradation has become a global challenge. As a main component of greenhouse gas, CO$_2$ emissions have soared in the last few decades (Dong et al. 2018a), as evidenced by an upsurge in global CO$_2$ emissions from 21,571.7 million metric tons in 1990 to 33,472.0 million metric tons in 2014, signifying the average growth rate of about 1.8% annually (BP 2017). People are emitting so much CO$_2$ into the air that the record of emissions over at least the past 50 million years will be set in the middle of this century (Foster et al. 2017).

Obviously, the escalating environmental degradation has facilitated environment protection awareness. Similarly, the impacts of economic activities on environmental degradation have turned into appealing topics for researchers (Cohen et al. 2018). According to EKC hypothesis, environmental degradation increases in line with the first stage of economic growth until reaching its peak and then decreases, which resembles an
inverted U-shaped curve. The rationale of EKC hypothesis can be summarized as follows: at the beginning, the economy grows without any change in its technology or structure, thus exacerbating the environment; when the economy continues to develop, there is an improvement towards more information-intensive industries that reduces pollution. Moreover, enhanced standard of living causes an upswing in demand for higher environmental quality, which also lessens pollution (Grossman and Krueger 1991). Virtually, most of the studies regarding the link between economic growth and pollution focus on CO$_2$ as an indicator of environmental degradation (Shahbaz and Sinha 2019). Hence, this paper utilizes CO$_2$ as an indicator of environmental degradation.

Besides testing EKC hypothesis, the connections among energy consumption, environmental, and economic growth have caught considerable attention of researchers and policy makers when the achievements of sustainable development have been internationally spotlighted (Antonakakis et al. 2017). Literature concerning the income-energy-environment relationship indicates that energy consumption and real income are among the main factors determining CO$_2$ emissions (Yavuz, 2014; Dogan and Turkekul 2016; Dogan et al. 2017). Also, as other variables can affect the aforementioned relationship (Al-mulali et al. 2015b), it is necessary to include additional factors to avoid omitted variables bias (Dogan and Turkekul, 2016).

Financial development is one of the crucial determinants of environmental degradation. Firstly, financial development attracts foreign direct investment (FDI) and facilitates gross domestic product (GDP) growth, which demands more energy usage (Mahalik et al. 2017). Secondly, effective financial intermediary process due to the development of the financial sector creates an increase in credit for goods and services purchase that consumes energy, thus damaging the environment (Sadorsky 2011). Thirdly, a developed financial system encourages capital that improves production capability, fosters energy demand, and then harms the environment (Charfeddine and Khediri 2016). On the other hand, Frankel and Romer (1999) argued that, during the financial development process, developing countries are motivated to apply more advanced and cleaner technology, thus reducing the impacts on the environment. In addition, they claim that financial development encourages companies to acquire capital and cuts costs by using environment-friendly technology. This argument is validated by Yuxiang and Chen (2011) stating that the stimulation of financial development policies is a key issue for fostering technological spillovers, hence diminishing CO$_2$ emissions and increases domestic production. Also, Cole and Elliot (2005) investigated the impacts of financial development on environmental degradation proxied by CO$_2$ emissions and showed that financial instruments such as loans, leasing, factoring, treasury bonds, and derivatives enable medium and big enterprises to achieve economies of scale, which contracts resource utilization and CO$_2$ emissions.

Over the last few years, the role and importance of globalization to many social aspects, politics, economics, and especially environmental degradation have been highlighted by policy makers and scholars (Shahbaz et al. 2018a; Phong 2019). Globalization is a worldwide phenomenon that removes or diminishes cross-border barriers, facilitates advanced technological transfer, and boosts investment and capital flow (Mishkin 2009). It creates financial development and promotes trade alongside economic activities through FDI and energy-saving technology exchange. The efficient use of energy owing to modern technology helps decrease energy consumption and improves environmental quality by CO$_2$ restriction (Saud et al. 2018). Notwithstanding, globalization is detrimental to the environment as it stokes up international commerce, investment, and other economic activities, which causes the upturn in energy consumption and environmental damage (Latif et al. 2018). Also, globalization expedites the spread of pollution via the trade of non-renewable resources to countries where environmental policies are insufficient. Antweiler et al. (2001) indicated that when the level of trade liberalization increases, governments had to lower production costs by ignoring or sacrificing the environment.

Besides, although it is undisputed that government can facilitate economic growth by expenditure and institutional quality (Barro 1990; Perera and Lee 2013), the connections among government expenditures, institutional quality, and environmental quality have not received much attention in the existing literature. López et al. (2011) provided theoretical bases for determining the channels through which government expenditures can directly and indirectly impact the environment. Specifically, the previously mentioned direct effect results from the consumption of energy and related products along with other polluting products of government agencies. However, government expenditure on public goods such as household subsidies and social transfers will cause income effect, thus leading to higher demand for “green products” and limit pollution. Meanwhile, the indirect effect is induced by government expenditure on public goods such as infrastructure (e.g., electricity, communication, and transport system) and the expansion in human and physical resources via medical and education. This stimulates output growth (scale effect) and influences environmental quality. However, the increase of human resource has less harmful impacts on the environment than the physical one, and this is called the composition effect. Moreover, public expenditure on R&D investment and knowledge popularization can activate the technique effect by which cleaner technology is developed (López et al. 2011). Besides, higher expenditure on establishing and implementing environmental regulations may enhance environmental quality. Nevertheless, expenditure on infrastructure often grows more rapidly than environmental regulations, which can degrade the environment (Ward et al. 2014). For institutions, Ostrom (1998) proposed that environmental conditions, and political action.
regulations were subject to governments’ policies which depend on the governments’ structure and efficiency measured by institutional quality. Institution quality can foster environmental quality and GDP growth by providing strong judicial system, creating effective mechanism for capital and information allocations and attracting foreign investment (Frankel and Romer 1999). Dal Bó and Rossi (2007) denoted that incremental institutional quality could lower CO2 emissions. The enhancement of resource allocation can also lessen CO2 emissions (Ebeke et al. 2015). Le et al. (2016), however, stated that when a nation lacked or had weak environmental regulations, some firms could consider it the “pollution haven” and exploit this opportunity to avoid high pollution control costs in their home countries. Shah et al. (2019) also argued that the growth process deteriorated because of low institutional quality that can increase risks and damage the environment.

From the aforesaid bases, environmental degradation has become a global challenge in the past several decades. The escalating environmental degradation has facilitated environment protection awareness. Hence, studies on the influential factors of environmental damage alongside the validation of EKC hypothesis have always attracted much attention because the implications of the research results are important for policy makers and other stakeholders in designing environmental policies. This study uses the sample of Emerging Market and Developing Economies (EMDEs) in the period 1990–2014 to scrutinize the impacts of globalization, financial development, institution, government expenditures, energy consumption, and economic growth on CO2 emissions in a multivariate framework in conjunction with verifying the presence of the EKC. The findings of this study can support policy makers to design effective environmental policies for EMDEs to achieve environmental sustainability.

This work contributes to the existing literature as follows: first, despite a large body of empirical documents about the impacts of several factors on environmental damage and the examination of EKC hypothesis, to the best of our knowledge, it seems that there is a research gap for the case of EMDEs. Thus, this study will supplement the existing literature and help increase the understanding of the environmental issues relating to EMDEs. Second, this article focuses on EMDEs that substantially contributed to the world’s input and consumption growth (about 70%) in the 2000–2015 period (Gruss et al. 2018). EMDEs are open and dynamic economies that have experienced rapid globalization process especially in terms of economic globalization through trade and investment (Gruss et al. 2018). Nevertheless, EMDEs are harmed by globalization and face negative effects in terms of environmental degradation because they have relatively low institutional quality and financial development as well as loose environmental protection standards (Ghosh 2010; Slesman et al. 2019). This article provides new insight into the role of globalization, financial development, and institutional quality as determinants of environmental degradation, which is suitable for the circumstances of EMDEs and thus helpful for the environmental policies in those countries. Third, our study employs a multivariate empirical model instead of a bivariate one, which corrects the potential unreliability of the latter, avoids omitted variables, and produces accurate results to test for the existence of EKC hypothesis (Pata 2018). Relating to this issue, to avoid model specification bias, besides traditional factors such as energy consumption and income level, this study emphasizes the role of several independent variables including globalization, financial development, institution, and government expenditure as important influential factors of CO2 emissions in the framework of EKC model. Finally, this study examines the heterogeneity and cross-sectional dependence issues that may occur within cross countries due to the failure to examine the mentioned issues in the estimation process, which possibly leads to unreliable outcomes (Pesaran 2004). By using parameter estimators and causality procedure via second-generation econometric techniques for heterogeneous panel, the findings of this paper pay more attention to useful policy implications.

The remaining content of this article is ordered as follows: the “Literature review” section covers crucial aspects of existing literature; the “Model, methodology, and data” section clarifies the estimation model, econometric methodology, and data collection applied in this paper; the “Empirical results” section displays explanations to the findings; and the “Conclusion and policy recommendations” section lists essential summaries of this paper and recommendations for policy makers based on the empirical findings.

**Literature review**

The past few decades witnessed the rapid development of economic activities which raised concerns about their impacts on the environment. More economic activities signify the augmentation of the people’s income, but the drawbacks are natural resources depletion and environmental degradation. The pioneering work of Grossman and Krueger (1991) analyzed the relationship between income level and environmental degradation based on the Environmental Kuznets Curve (EKC) assuming an inverted U-shaped effect of income per capita on pollution. After Grossman and Krueger (1991), the majority of empirical studies on environmental economics have focused on testing the EKC hypothesis in different countries, and their findings are not unanimous (see Table 9).

The literature in recent decades shows that although manifold studies have supported the EKC hypothesis, it remains a hot and controversial topic because some aspects still need to be thoroughly analyzed. First, empirical findings are very sensitive to the samples of selected countries and time (Stern 2004; Riti et al. 2017). Second, the results regarding the
EKC hypothesis are biased in case of omitted variables and inappropriate econometric techniques (Al-mulali et al. 2015b; Solarin et al. 2017). Third, as EKC is a dynamic mechanism often impacted by institution, policy, globalization, or higher development level (Shahzad et al. 2017; Farzanegan and Markwardt 2018), strong econometric methods alongside the careful analysis of explanatory variables can provide much improvement in the research outcomes (Dar and Asif 2018b). In the following paragraphs, we review the factors influencing environmental degradation besides the relationship between economic growth and environmental degradation described by the EKC hypothesis.

Economic growth goes in line with higher energy demand, thus worsening the environment (Shahbaz et al. 2017). The literature on energy-income-environment connections contains a large number of articles that investigated the existence of the EKC hypothesis. For example, Pao and Tsai (2011) inspected the effects of energy consumption and economic growth on CO2 emissions and reported the occurrence of EKC in BRIC countries during 1971–2005, which indicated that energy consumption and economic growth were the stimulants to CO2 emissions. Jaunky (2011) researched 36 high-income countries from 1980 to 2005 and found the positive link between energy consumption and CO2 emissions; besides, the EKC hypothesis was confirmed in Greece, Malta, Portugal, Oman, and the United Kingdom. Shahbaz et al. (2014) utilized ARDL method and VECM Granger causality test and detected EKC in Tunisia between 1971 and 2010, together with the negative influence of energy consumption on CO2 emissions. Rehman and Rashid (2017) examined the role of energy consumption in environmental damage by the multivariate model in SAARC countries, pointed out the harmful impact of energy consumption on the environment, and validated the EKC hypothesis. Riti et al. (2017) investigated the connections among CO2 emissions, economic growth, and energy consumption in China over the 1970–2015 period and acknowledged the proof of EKC based on different techniques. Zhang et al. (2017) proved the EKC hypothesis in 10 newly industrialized countries (NIC-10) from 1971 to 2013 and concluded that when trade openness reduced CO2 emissions, real GDP and energy consumption demonstrated opposite effects.

The financial sector is essential for the development and stability of an economy. The relationship between financial development and CO2 emissions has been inspected by recent studies. Tamazian et al. (2009) examined the links among financial development, economic growth, and CO2 emissions in BRIC countries between 1992 and 2004 and exhibited the evidence of EKC and the culprits for the negative impact of financial development on CO2 emissions. Jalil and Feridun (2011) researched how financial development, economic growth, and energy consumption determined CO2 emissions in China and observed that financial development did not raise CO2 emissions. Ozturk and Acaravci (2013) spotted the sign of EKC in Turkey between 1960 and 2007 and found no association between financial development and CO2 emissions. Boutabba (2014) analyzed the long-run equilibrium among CO2 emissions, financial development, economic growth, energy consumption, and trade openness in India, offered support for the long-run and causal relationships among the majority of the aforementioned variables, and witnessed that financial development and energy consumption encouraged CO2 emissions. Farhani and Ozturk (2015) observed no trace of EKC in Tunisia between 1971 and 2012 and documented the harmful effects of urbanization, real GDP, trade openness, financial development, and energy consumption on the environment. Al-Mulali et al. (2015a) inspected the association of urbanization, trade openness, economic growth, financial development, renewable energy, and environmental damage in 23 European countries from 1990 to 2013 and found that only trade openness could reduce pollution while other factors contributed to environmental degradation. Javid and Sharif (2016) evaluated the importance of economic growth, financial development, and energy use to CO2 emissions in Pakistan over the 1972–2013 period using ARDL model, which spotted the trace of EKC and concluded that all the explanatory variables caused more severe pollution. Dogan and Turkekul (2016) rejected the EKC hypothesis in the USA, affirmed the positive impact of trade on the environment, showed no effect of financial development on pollution, and observed the damaging influences of energy consumption and urbanization on environmental quality. Dogan and Seker (2016) supported the EKC assumption for OECD countries, acknowledged the enhancement effects of openness and financial development on environmental quality, and discovered that energy consumption increased pollution. Solarin et al. (2017) indicated that the environment in Ghana deteriorated under the influences of urbanization, economic growth, financial development, and energy consumption during the 1980–2012 period. Xing et al. (2017) employed the STIRPAT model along with ARDL method and displayed the worsened environmental quality in China resulting from financial development. Shahzad et al. (2017) found that, between 1971 and 2011, the CO2 emissions in Pakistan were stimulated by financial development, as evidenced by the results of ARDL estimation in short-run and long-run. Dar and Asif (2018b) discovered that financial development and energy utilization augmented greenhouse gas emissions while economic growth was harmless to the environment in India. Salahuddin et al. (2018) documented, from the results of ARDL and VECM Granger causality analysis, that the environmental degradation in Kuwait between 1980 and 2013 was facilitated by economic growth, foreign direct investment, financial development, and electricity consumption.

In recent years, besides the association between energy consumption and financial development, some studies have...
verified the EKC hypothesis with the inclusion of several new important factors such as globalization, institution, and government expenditure. The time, scope econometric methods, and findings, however, vary from article to article. For instance, Shahbaz et al. (2013) incorporated globalization, economic growth, and energy density into CO₂ emission analysis by ARDL and VECM Granger methods and found that the environmental quality in Turkey between 1970 and 2010 was improved by globalization and damaged by economic growth and energy density; also, the EKC hypothesis was supported. Shahbaz et al. (2015) demonstrated that globalization, economic growth, financial development, and energy consumption impaired the environmental quality in India from 1970 to 2012 and provided evidence for EKC. Shahbaz et al. (2018b) noticed that the CO₂ emissions in 25 developing countries were boosted by globalization in the 1970–2014 periods, thus reinforcing the positive relationship between globalization and pollution. Haseeb et al. (2018) confirmed the occurrence of EKC in BRICS countries reported no causal effects of globalization and urbanization on CO₂ emissions and witnessed that financial development and energy consumption caused pollution. Phong et al. (2018) investigated the impacts of globalization, GDP per capita, industrialization, urbanization, and energy consumption on the environment in Vietnam during the period 1985 to 2015 employing ARDL method and concluded that globalization reduced CO₂ emissions while GDP per capita, industrialization, and energy consumption had reverse effects, which provided some implications for policy makers to promote sustainable development strategies in Vietnam. Continuing the previous research, Phong (2019) assessed how globalization, GDP per capita, urbanization, financial development, and energy consumption influenced CO₂ emissions in selected ASEAN countries from 1971 to 2014 by applying fixed and random effect regression models, underpinned EKC hypothesis in ASEAN-5 nations, and indicated that apart from GDP per capita all variables, especially globalization, induced more serious pollution. Zafar et al. (2019) applied CUP-FM and CUP-BC methods to gauge the impacts of globalization and financial development on the pollution in some OECD countries from 1990 to 2014 and recognized that both the previously mentioned factors enhanced the environmental quality; besides, energy consumption raised CO₂ emissions and the EKC hypothesis was supported. Salahuddin et al. (2019) certified insignificant effect of globalization on CO₂ emissions in 44 sub-Saharan Africa countries in the period 1984–2016. A small proportion of existing literature is devoted to measure to what extent institutions and government expenditure affect environmental degradation. Tamazian and Rao (2010) investigated the impacts of institution and financial development on environmental quality and found that financial liberalization harmed the environment when lacking strong institutional framework. This is the reason why governments should establish effective policies to foster advanced technology, which helps reduce CO₂ emissions. Another study by Abid (2016) acknowledged the importance of institutional framework and financial development in cutting CO₂ emissions in sub-Saharan economies. Adewuyi (2016) evaluated the impact of government expenditure on pollution in top 40 countries emitting CO₂ from 1990 to 2015. The findings denoted that 1% increase in government expenditure caused 0.034% rise in overall CO₂ emissions in the long-run. Moreover, the same level increase in government expenditure changed the CO₂ emissions in transportation and production sectors by −1.1% and 0.1% respectively. Chaabouni et al. (2016) analyzed the relationships among economic growth, health expenditure, and CO₂ emissions in 51 countries between 1995 and 2013, which indicated the two-way causality between economic growth and CO₂ emissions. Also, there were a two-way causation between economic growth and health expenditure and a one-way effect from CO₂ emissions to health expenditure. The aforementioned findings hold true for middle- and high-income countries and confirmed the occurrence of EKC phenomenon. Farzanegan and Markwardt (2018) analyzed the case of the Middle East and North Africa regions and reported that government expenditure could effectively reduce CO₂ emissions, but it depended on the institutional quality. Solarin et al. (2017) conducted the research for Ghana and found that institutional quality helped lower CO₂ emissions. Mohammed Saud et al. (2019) studied how government expenditure and financial development affected environmental degradation in Venezuela from 1971 to 2013 using ARDL method and found that government expenditure stimulated pollution while financial development improved environmental quality. Yuelan et al. (2019) studied the effects of fiscal policy tools such as government expenditures and total revenue, together with GDP and energy usage, on China’s environmental degradation in the period 1980–2016, which demonstrated that all the aforesaid variables worsened the environmental quality. Thus, the role of the government, especially in terms of expansionary fiscal policy, can boost environmental degradation. In summary, the review of literature demonstrates that the impacts of relevant factors on CO₂ emissions within the EKC hypothesis framework are unclear. This indicates the complexity of EKC verification that is subject to methods, time, and data (Destek and Sarkodie, 2019). It is obvious that there has been no empirical study of the relationships among globalization, financial development, government expenditure, institutional quality, energy consumption, and economic growth on CO₂ emissions in EMDEs using the EKC framework. Consequently, this article fills the aforesaid research gap by employing various econometric techniques.
Model, methodology, and data

Model specification

In order to test the validity of EKC hypothesis, the relationship between CO₂ emissions, GDP, and energy usage (Ang 2007; Pao et al. 2011; Riti et al. 2017) is modeled as follows:

\[ CO_2 = f(GDP, GDP^2, EC) \]  

(1)

As mentioned in the introduction part, financial development lowers credit limitation in the economy, increases the purchase of goods and services that consume energy, and facilitates investment, which boosts energy usage and aggravates environmental quality (Sadorsky, 2011; Zhang 2011; Charfeddine and Khediri 2016). On the other hand, financial development directs investment towards modern and clean technology and thus helps reduce CO₂ emissions (Tamazian et al. 2009; Zafar et al. 2019).

Government expenditure is also a remarkable determinant of environmental degradation (López et al. 2011; López and Palacios, 2014). The mechanism that government expenditure impacts the environment relates to the scale effect, composition effect, technique effect, and income effect. The scale effect reflects the accrual of physical and human resources that stimulates GDP growth but worsens environmental quality. The composition effect demonstrates that expenditure on physical resource produces more negative influence on the environment than the human counterpart. The technique effect is activated by more investment in R&D and knowledge popularization, which promotes cleaner energy and diminishes the damage to the environment (López et al. 2011). The income effect emphasizes the link between higher government expenditure and higher demand for improving environmental quality (Yuelan et al. 2019).

Besides, a strong institutional framework is useful for controlling pollution because it allows the government to provide environmental regulations, allocate capital effectively, ensure information transparency, and monitor manufacturing, commercial, and investment activities (Dal Bó and Rossi 2007; Padda và Asim 2019). In contrast, bad institutional quality can result in more economic risks and damage the environment (Le et al. 2016; Shah et al. 2019).

Another determinant of CO₂ emissions employed in this article is globalization. Globalization can impact environmental quality via scale effect, technique effect, and composition effect (Grossman and Krueger 1991). The scale effect happens when globalization boosts economic activities, which consumes more energy and causes pollution (Dreher, 2006). The technique effect of globalization refers to the transfer and application of modern technology in commerce and investment that limit CO₂ emissions (Zafar et al. 2019). The composition effect occurs when more carbon-intensive goods are produced due to the enhancement of production and investment, thus damaging the environment. Nevertheless, the transition of economic structure from heavy industry to light and service ones can improve the environment quality.

Based on the review of literature, especially recent studies of Shah et al. (2019), Yuelan et al. (2019) and Zafar et al. (2019), this article includes globalization, financial development, government expenditure, and institution to examine the Environmental Kuznets Curve (EKC) in EMDEs:

\[ CO_2 = f(GDP, GDP^2, EC, GC, QoG, KOF, FD) \]  

(2)

where CO₂, GDP, GDP², EC, GC, QoG, KOF, and FD respectively denote CO₂ emissions per capita, GDP per capita, square of GDP per capita, primary energy consumption per capita, general government final consumption expenditure, institution quality, globalization, and financial development.

The author transforms all variables into natural logarithms to decrease dispersion, multicollinearity, and heteroscedasticity in the data (Dar and Asif 2018a; Solarin et al. 2017). Hence, the log-linear regression can generate more efficient and consistent outcomes than the simple linear equation (Sinha and Shahbaz 2018).

Equation (2) is changed into the log-linear specification as follows:

\[ \ln CO_{2,t} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP^2_{it} + \beta_3 \ln EC_{it} + \beta_4 \ln GC_{it} + \beta_5 \ln QoG_{it} + \beta_6 \ln KOF_{it} + \beta_7 \ln FD_{it} + \epsilon_{it} \]  

(3)

where \( i \) denotes the country (\( i = 1, 2, ..., 47 \)), \( t \) indicates the time period (1990–2014), \( \epsilon_{it} \) is the error term, and the coefficients \( \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \) and \( \beta_7 \) reflect the impacts of the independent variables on the dependent one.

Econometric methodology

Cross-sectional dependence (CD) and slope heterogeneity issues may arise in econometric analysis of country panel data (Dogan and Seker 2016). As a result, it is important to check for the aforementioned problems before selecting the appropriate methods.

The procedure of panel data estimation can be summarized by the following steps: unit root test, cointegration test, regression estimation, and causality analysis. Traditional methods, also known as “first-generation” methods, can be instanced as: IPS, LLC, ADF, and PP unit root tests; Johansen (1988), Kao (1999), and Pedroni (1999) cointegration tests; ordinary least squares (OLS), dynamic OLS (DOLS), and fully modified OLS (FMOLS) regression estimation; and Granger causality techniques. Although the aforesaid “first-generation” econometric techniques are widely employed, their weaknesses stem from cross section independence assumption (Dogan...
and Seker 2016). When cross-sectional dependence and slope heterogeneity exist, they are biased and unreliable (Pesaran 2004; Breitung 2005; Dogan and Seker, 2016). In such case, “second-generation” econometric techniques are appropriate for heterogeneous panel.

Thus, the estimation procedure in this article is implemented through six important steps. First, the CD test provided by Pesaran (2004) is conducted. Second, the slope homogeneity test introduced by Pesaran and Yamagata (2008) is applied. Third, after validating CD, it is necessary to use the CADF and the CIPS panel unit root test to inspect the stationarity of each variable. Fourth, in order to examine cointegration among all the selected variables, the Westerlund panel cointegration tests and Banerjee and Carrion-i-Silvestre (2017) cointegration tests are necessitated. Fifth, the panel AMG (Eberhardt and Teal, 2010), CCEMG (Pesaran 2006), and DCCE (Chudik and Pesaran, 2015) estimators are employed to evaluate the parameters of the independent variables. Finally, Dumitrescu-Hurlin (D-H) panel causality (Dumitrescu and Hurlin, 2012) method will illuminate the causation among variables.

Cross-sectional dependence test

In panel data analysis, CD can happen due to the interactions among the countries in the same economic-social network, space effects, and other unobserved factors (Chudik and Pesaran 2013). Failure to address CD in panel data will produce biased and inconsistent estimation results (Dong et al. 2018b; Phillips and Sui 2003).

To investigate the CD in panel data, the LM test grounded in Breusch and Pagan (1980) is widely employed, which is displayed as follows:

\[ Y_{it} = \alpha_i + \beta_i X_{it} + \varphi_{it} \]  

where \( i = 1, 2, \ldots, N \) indicates cross-section dimension, \( t = 1, 2, \ldots, T \) represents time dimension, and \( X_{it} \) is a \( k \times 1 \) vector of independent variables.

The null and alternative hypotheses of cross-sectional dependence are \( H_0 : \text{Cov}(\varphi_{it}, \varphi_{jt}) = 0 \) and \( H_1 : \text{Cov}(\varphi_{it}, \varphi_{jt}) \neq 0 \) respectively, which is chosen by the following LM test:

\[ \text{LM} = T \sum_{t=1}^{N-1} \sum_{j=t+1}^{N} \hat{\rho}_{ij} \]  

Notwithstanding, the LM test may be biased. Pesaran (2004), therefore, modified it by adjusting for the biases based on the LM statistic mentioned in Breusch and Pagan (1980) as following:

\[ \text{CD} = \sqrt{\frac{2T}{N(N-1)} \sum_{t=1}^{N-1} \sum_{j=t+1}^{N} (T-k)\hat{\rho}_{ij}^2 - E[(T-k)\hat{\rho}_{ij}^2]} \]  

where \( \hat{\rho}_{ij} \) represents the coefficient of pair-wise correlation obtained from OLS using Eq. (4) for each cross-section dimension \( i \). Furthermore, \( T \) and \( N \) are sample and panel sizes respectively.

Slope homogeneity test

If there exists considerable cross-sectional dependence, each country may have similarities in terms of economic development movement. Accordingly, controlling for the cross-sectional heterogeneity is necessary. Otherwise, the estimation outcomes are untrustworthy (Breitung 2005).

Swamy (1970) recommended a method for investigating the slope homogeneity phenomenon, which employs a pooled estimator to capture the variability of the estimated individual regression coefficients. The null hypothesis assumes that the slopes (i.e., individual regression coefficients) are homogeneous. The alternative hypothesis states that they are heterogeneous. For big panel data, Pesaran and Yamagata (2008) expanded the method of Swamy (1970) to validate the slope homogeneity, which can be illustrated as follows:

\[ \bar{S} = \sum_{i=1}^{N} \left( \beta_i - \bar{\beta}_{\text{WFE}} \right)^2 \frac{X_i'M_iX_i}{\sigma_i^2} \left( \beta_i - \bar{\beta}_{\text{WFE}} \right) \]  

where \( \bar{\beta} \) denotes the pooled OLS regression coefficients for each individual \( i \) ranging from 1 to \( N \), and \( \bar{\beta}_{\text{WFE}} \) represents the weighted fixed effect (WFE) pooled estimator of slope coefficients. Additionally, \( M_i \) indicates the identity matrix and \( \sigma_i^2 \) is an estimate of \( \sigma_i^2 \). The standardized dispersion statistic \( \bar{\lambda} \) and the biased-adjusted version \( \bar{\lambda}_{adj} \) are defined by:

\[ \bar{\lambda} = \sqrt{N} \left( \frac{N^{-1}S-k}{\sqrt{2k}} \right) \]  

\[ \bar{\lambda}_{adj} = \sqrt{N} \left( \frac{N^{-1}S-E(\tau_k)}{\sqrt{\text{var}(\tau_k)}} \right) \]  

where \( E(\tau_k) = k \) and \( \text{var}(\tau_k) = \frac{2k(T-k-1)}{T+1} \).

Panel unit root test

Panel unit root tests such as LLC, IPS, ADF, and PP tests are frequently used for checking stationarity of the variables. Nonetheless, when CD exists, the first generation of panel unit root tests as previously mentioned is unreliable (Pesaran 2007). In contrast, the second generation of panel unit root tests developed by Pesaran (2007) such as the CADF and
CIPS panel unit root tests is robust. Therefore, the author utilizes CADF and CIPS tests. The CADF statistic can be written as follows:

\[
\Delta Y_{it} = \alpha_i + \beta_i Y_{it-1} + \gamma_i \bar{Y}_{t-1} + \delta_i \Delta \bar{Y}_{it} + \varepsilon_{it}
\]

where

\[
\bar{Y}_{t-1} = \frac{1}{N} \sum_{i=1}^{N} Y_{i,t-1}; \Delta \bar{Y}_{it} = \frac{1}{N} \sum_{i=1}^{N} \Delta Y_{i,t}
\]

Pesaran (2007) introduced CIPS computed by averaging the CADFi as follows:

\[
\text{CIPS} = \frac{1}{N} \sum_{i=1}^{N} \text{CADFi}
\]

In eq. 12, CADF denotes the CADF statistic for each cross-sectional individual \( t \) based on the \( t \) ratios of \( \beta \), shown in eq. 10.

### Panel cointegration test

The long-run relationships among variables can be illuminated by cointegration test. If there exists cross-sectional dependency, normal cointegration tests such as Johansen or Kao generate biased and thus unreliable estimates. Consequently, this article applies the Westerlund panel cointegration tests (Westerlund 2007) to investigate the cointegration of the variables. Correspondingly, the error correction specification is given as:

\[
\Delta Y_{it} = \delta_i d_t + \varepsilon_i \left( Y_{i,t-1} - \beta_i X_{i,t-1} \right) + \sum_{j=1}^{p} \varphi_j Y_{i,t-j} + \sum_{j=0}^{d} \varphi_j X_{i,t-j} + \mu_{it}
\]

in which \( \varepsilon_i \) is the coefficient representing the speed of correction towards equilibrium.

Westerlund (2007) proposed 4 formulas including group mean statistics and panel statistics, which are displayed in equations (14) to (17).

\[
G_{\tau} = \frac{1}{N} \sum_{i=1}^{N} \frac{\varepsilon_i}{\text{Se}(\bar{\varepsilon})}
\]

(14)

\[
G_{\alpha} = \frac{1}{N} \sum_{i=1}^{N} \frac{T \varepsilon_i}{\text{Se}(\bar{\varepsilon}_1)}
\]

(15)

\[
P_{\tau} = \frac{\bar{\varepsilon}_i}{\text{Se}(\bar{\varepsilon})}
\]

(16)

\[
P_{\alpha} = T \bar{\varepsilon}
\]

(17)

All the statistics are calculated from the least squares estimates of \( \varepsilon_i \) and the time dimension \( T \). Moreover, the \( G_{\tau} \) and \( G_{\alpha} \) statistics are used to judge whether cointegration happens in at least one cross-sectional unit or not, whereas the \( P_{\tau} \) and \( P_{\alpha} \) ones indicate whether cointegration exists in the whole panel or not.

In this article, the author also uses the cointegration test lately introduced by Banerjee and Carrion-i-Silvestre (2017) which assumes that cross-sectional dependence is associated with common factors evaluated by the averages of each variable in the cross section. The cointegration test of Banerjee and Carrion-i-Silvestre (2017) is flexibly used for different \( T \) and \( N \) combinations and allows structural breaks in the panel data.

The estimator CCEMG (Pesaran 2006) can be utilized for the test as follows:

\[
Y_{it} = \alpha_i + \beta_i X_{it} + \delta_i Z_{it} + \tau_{it}
\]

In equation (18), \( Z_t = \left( \bar{Y}_t, \bar{X}_t, \right)^T \) is a \( (m+1) \times 1 \) vector computed from the cross-section averages of the dependent variable and the stochastic regressors.

### Heterogeneous parameter estimates

As mentioned in the preceding parts, CD can lead to invalid stationarity tests and estimation results (O’Connell 1998). Given the presence of CD, OLS, and GLS methods produce biased estimates (Phillips and Sul 2003). Also, popular models such as fixed effects (FE) and random effects (RE) suffer from inconsistency and untrustworthiness when exposed to cross-sectional dependence (Sarafidis and Robertson 2009). Furthermore, normal estimators are also inconsistent when the culprits of cross-sectional dependence relate to independent variables.

Pesaran (2006) introduced the CCEMG estimator that was upgraded by Kapetanios et al. (2011). The CCEMG estimator includes the averages of independent and dependent variables together with the unobserved common factors \( f_i \) as shown in eq. (19), which ensures robustness regardless of CD and slope homogeneity (Atasoy 2017; Kapetanios et al. 2011).

\[
Y_{it} = \alpha_i + \beta_i X_{it} + \gamma_i \bar{Y}_{it} + \delta_i \bar{X}_{it} + c_{if} + \varepsilon_{it}
\]

(19)

where it \( Y_{it} \) and \( X_{it} \) are variables; \( \beta_i \) is the country-specific slope; \( f_i \) is the unobserved common factor with heterogeneous factor loadings; \( \alpha_i \) and \( \varepsilon_{it} \) represent the intercept and error term respectively.

Besides CCEMG, this study employs AMG estimator introduced by Eberhardt and Bond (2009) and Eberhardt and Teal (2010) because it is highly robust in spite of CD and parameter heterogeneity. The AMG method deals with the unobservable common factors \( f_i \) mentioned in eq. 19 by using the common dynamic effect parameter, which enables helpful
interpretations. To illustrate the AMG estimator, consider this OLS equation at first difference:

\[ \Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + \sum_{j=1}^{T} \theta_j D_j + \varphi_i f_i + \varepsilon_{it} \]  

(20)

where \( \Delta \) is difference operator and \( \theta \) represents the coefficients of the time dummy \( D \).

Next, the group-specific regression model is augmented by assigning a unit coefficient to each group member, and the group-specific parameters are averaged across the panel:

\[ \text{AMG} = \frac{1}{N} \sum_{i=1}^{N} \bar{\beta}_i \]  

(21)

where \( \bar{\beta}_i \) are the estimates of \( \beta_i \) in eq. 20.

According to Bond and Eberhardt (2013), the results estimated by AMG technique in Monte Carlo simulation are unbiased and efficient for various combinations of observations \( N \) and time \( T \).

Besides, this study also employs a recent approach called “Dynamic Common Correlated Effects” (DCCE) estimator proposed by Chudik and Pesaran (2015) to assess the impacts of the lagged values of the dependent variable for heterogeneous panel. The DCCE estimator is better than the CCEMG one because it allows dynamics in the panel (i.e., permits the lagged values of the dependent variables as regressors).

**Panel causality tests**

Dumitrescu and Hurlin (2012) proposed the test for non-causality hypothesis by modifying Granger (1969) non-causality test as follows:

\[ Y_{i,t} = \alpha_i + \sum_{k=1}^{P} \gamma_{ik} Y_{i,t-k} + \sum_{k=1}^{P} \beta_{ik} X_{i,t-k} + \mu_{i,t} \]  

(22)

In equation 22, \( Y_{it} \) and \( X_{it} \) are the variables observed for individual \( i \) (\( i = 1, 2, \ldots, N \)) at time \( t \) (\( t = 1, 2, \ldots, T \)); the lag length \( P \) is a positive integer; \( \gamma_{ik} \) denotes autoregressive parameters; and \( \beta_{ik} \) represents the regression coefficients. Moreover, \( \beta_{ik} \) is assumed to differ across individuals and time-invariant. Furthermore, the panel data is presumed to be balanced and the lag length \( P \) is the same for all individuals.

The null hypothesis of non-causality among the variables for all individuals can be specified as follows:

\[ H_0 : \beta_{i1} = \beta_{i2} = \ldots = \beta_{ip} = 0, \forall i = 1, 2, \ldots, N \]  

(23)

The alternative hypothesis, also known as the heterogeneous non-causality hypothesis, states that causation can happen for some individuals but not necessarily all of them, which can be written as follows:

\[ H_1 : \beta_{i1} = \beta_{i2} = \ldots = \beta_{ip} = 0, \forall i = 1, 2, \ldots, N_1 \]  

(24)

\[ \beta_{i1} \neq 0 \text{ or } \beta_{i2} \neq 0, \ldots, \text{ or } \beta_{ip} \neq 0 \forall i = N_1 + 1, N_1 + 2, \ldots, N \]  

(25)

where \( N_1 \) is a natural number that satisfies \( 0 \leq \frac{N_1}{N} \leq 1 \).

Dumitrescu and Hurlin (2012) suggested regressing eq. 22 for \( N \) individuals and conducting \( F \) test for \( K \) linear hypotheses \( \beta_{i1} = \beta_{i2} = \ldots = \beta_{ip} = 0 \) and then averaging the Wald statistics for \( N \) individuals:

\[ \overline{W} = \frac{1}{N} \sum_{i=1}^{N} W_i \]  

(26)

In eq. 26, \( \overline{W} \) is the average statistics of the null homogeneous noncausality hypothesis, and \( W_i \) is the individual Wald statistics in time \( T \).

The individual Wald statistics collectively form a chi-squared distribution with \( P \) degrees of freedom when \( T \rightarrow \infty \).

### Table 1 Variable description and data sources

| Variables               | Symbol | Description                                                                                       | Unit                          | Data source                              |
|-------------------------|--------|--------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------|
| CO₂ emissions           | CO₂    | CO₂ produced during consumption of solid, liquid, and gas fuels and gas flaring                   | Metric tons per capita        | WDI                                      |
| Energy consumption      | EC     | It comprises petroleum products, natural gas, electricity, and combustible renewable and waste    | Kg of oil equivalent per capita | WDI                                      |
| GDP per capita          | GDP    | The GDP by the midyear population                                                                | Constant 2010 US dollars      | WDI                                      |
| Government expenditures | GC     | General government final consumption expenditure                                                 | % of GDP                      | WDI                                      |
| Institutions            | QoG    | Quality of Government Index                                                                      | Index (from 0 to 1)           | The Quality of Government Institute, University of Gothenburg, Sweden |
| Globalization           | KOF    | The globalization is measured with economic, social, and political indices as defined by (Dreher 2006) | Index (from 0 to 100)         | KOF Swiss Economic Institute             |
| Financial development   | FD     | The domestic credit to the private sector                                                        | % of GDP                      | WDI                                      |
$∞$. The standardized $Z$ statistic computed from $W$ and $P$ could be proved to follow standard normal distribution:

$$Z = \sqrt{\frac{N}{2P} (W - P)} \rightarrow N(0, 1) \tag{27}$$

Dumitrescu and Hurlin (2012) indicated that the harmonized $Z$ test statistic (i.e., $\bar{Z}$ displayed in eq. 28) which is adjusted for fixed $T$ sample also has standard normal distribution property:

$$\bar{Z} = \sqrt{\frac{N}{2P} X \left(\frac{T-2P-5}{T-2P-3} - \frac{T-2P-3}{T-2P-1}\right) (W - P)} \rightarrow N(0, 1) \tag{28}$$

### Data

This article analyzes the annual data from 1990 to 2014 for 47 Emerging Market and Developing Economies (see Table 10). CO$_2$ emissions per capita (metric tons) are used as a proxy for environmental pollution by the majority of studies (Stern 2004; Lean and Smyth 2010; Shahbaz and Sinha 2019). Concerning the selection and measurement of independent variables, based on Dogan and Seker (2016), Haseeb et al. (2018), and Yuelan et al. (2019), the author uses real GDP per capita in constant 2010 dollars and energy consumption in kilogram of oil equivalent per capita. Also, financial development is defined by the ratio of domestic credit to private sector as a share of GDP. Meanwhile, government expenditure means the general government final consumption expenditure as a share of GDP. The aforementioned data are retrieved from the World Development Indicators (2018).

This paper uses KOF Globalization Index (KOF) which was developed by Dreher (2006) and obtained from KOF Swiss Economic Institute as a proxy for globalization. In addition, the KOF Globalization Index is a composite of several indicators of economic, political, and social aspects of globalization, which varies from 0 to 100 with higher value indicating higher level of globalization. KOF de facto economic globalization includes trade and financial globalization. Trade globalization is determined by trade openness (the sum of exports and imports of goods and services as a share of GDP) and a variable that captures partners’ diversification in the trade of goods. Financial globalization is measured by capital flows and stocks of foreign assets and liabilities. Social globalization is

| Variables | Mean | SD | Min | Max |
|-----------|------|----|-----|-----|
| lnFD      | 3.279| 0.808| 0.480| 5.115|
| lnKOF     | 3.795| 0.192| 3.334| 4.377|
| lnEC      | 6.691| 0.798| 4.749| 9.426|
| lnGDP2    | 65.744| 16.008| 25.873| 100.828|
| lnKOF     | 3.985| 0.192| 3.334| 4.377|
| lnFD      | 3.279| 0.808| 0.480| 5.115|

### Table 4 Slope homogeneity test results

| Variable | $\bar{X}$ | $\bar{X}_{adj}$ |
|----------|-----------|-----------------|
| lnFD     | 143.521***| 275.520***     |
| lnKOF    | 127.565***| 280.502***     |
| lnGDP    | 113.618***| 931.401***     |
| lnKOF    | 133.690***| 893.973***     |
| lnFD     | 740.392***| 893.973***     |
| lnKOF    | 698.412***| 968.745***     |
| lnFD     | 67.399*** | 949.119***    |
| lnGDP    | 65.744*** | 100.828***    |

### Table 5 Panel unit root tests results

| Variables | CADF test statistic | CIPS test statistic |
|-----------|---------------------|---------------------|
|           | Level | First difference | Level | First difference |
| lnFD      | −2.466 | −3.318*** | −2.257 | −4.389*** |
| lnKOF     | −2.269 | −2.725*** | −2.498 | −4.779*** |
| lnQoG     | −2.427 | −2.681*** | −2.581 | −4.514*** |
| lnGC      | −2.144 | −3.211*** | −2.285 | −4.469*** |
| lnEC      | −2.024 | −3.594*** | −2.204 | −4.842*** |
| lnGDP2    | −2.370 | −2.785*** | −2.281 | −4.026*** |
| lnGDP     | −2.397 | −2.773*** | −2.294 | −4.039*** |
| lnFD      | 740.392***| 893.973***| 893.973***| 893.973*** |
| lnKOF     | 698.412***| 968.745***| 968.745***| 968.745*** |
| lnFD      | 143.521***| 275.520***| 275.520***| 275.520*** |

***Indicates significance at 1% level. The null hypothesis is no heterogeneity

### Table 3 The results of CD test

| Variable | CD test | $P$ value |
|----------|---------|-----------|
| lnFD     | 3.279***| 0.000     |
| lnKOF    | 3.795***| 0.000     |
| lnEC     | 6.691***| 0.000     |
| lnGDP2   | 65.744***| 0.000   |
| lnGDP    | 113.618***| 0.000   |
| lnKOF    | 3.985***| 0.000     |
| lnFD     | 3.279***| 0.000     |

***Indicates significance at 1% level. The null hypothesis is no CD
measured by interpersonal globalization, informational globalization, and cultural globalization. Political globalization is gauged by the political connections in organizations and treaties as well as the number of embassies of a country (Dreher 2006). Therefore, KOF is very appropriate for empirically analyzing the relationship between globalization and CO2 emissions instead of trade openness which was traditionally used in prior researches because it encompasses all aspects of globalization (economic, social, and political) (Shahbaz et al. 2018b).

The data about institutional quality is derived from The Quality of Government Institute, University of Gothenburg, Sweden. It is computed as the mean value of the ICRG variable corruption, law and order, and bureaucracy quality, and scaled from 0 to 1; the higher value signifies higher institutional quality. Table 1 displays information about the variables and their sources.

Table 2 provides some descriptive statistics such as mean, standard deviation (SD), and maximum (Max) and minimum (Min) values of the variables under natural logarithm.

### Empirical results

#### Results of cross-sectional tests

It is of vital importance to check cross-sectional dependence by Pesaran (2004) CD test. The results shown in Table 3 prove that cross-sectional dependence occurs with regard to all variables as the null hypothesis is rejected by the extremely low p values.

#### Results of slope homogeneity tests

Pesaran and Yamagata (2008) test is helpful to inspect the heterogeneity of slope coefficients. The existence of slope heterogeneity in the data is evidenced in Table 4.

#### Results of panel unit roots

After validating the occurrence of CD and slope heterogeneity, the CADF and CIPS unit root tests (Pesaran 2007) are appropriate for assessing the stationarity of the variables. Table 5 reveals that all variables are stationary at first difference. In other words, they are integrated at order 1, which can be denoted as I(1).

#### Results of panel cointegration tests

As cross-sectional dependence, slope heterogeneity and the order of integration of the variables have been confirmed, the robust Westerlund (2007) and Banerjee and Carrion-i-Silvestre (2017) cointegration tests are employed to detect the long-run relationships among the variables. The outcomes are reported in Table 6, which demonstrates the stable long-term relationship among the variables.

### Table 6 The cointegration test results

|                      | Westerlund (2007) | Banerjee and Carrion-i-Silvestre (2017) |
|----------------------|-------------------|----------------------------------------|
|                      | Statistics        | Value                                  | Z value | Robust P value | Lags | t statistic |
|                      |                   | -2.920***                              | -1.966  | 0.008          | 0    | -4.615***   |
|                      |                   | -10.984***                             | 3.319   | 0.000          | 1    | -5.147***   |
|                      |                   | -18.094**                             | -1.689  | 0.025          | 2    | -4.942***   |
|                      |                   | -8.821**                              | 2.052   | 0.040          |      |            |
|                      |                   |                                        |         |               |      |            |

*****The symbols and respectively denote the rejection of the null hypothesis at 5% and 1% levels.

### Table 7 AMG, CCEMG, and DCCE estimation results

| Regressors | AMG     | CCEMG    | DCCE    |
|------------|---------|----------|---------|
|            | Coefficient | t statistic | Coefficient | t statistic | Coefficient | t statistic |
| lagged lnCO2| 2.292***   | 5.84      | 2.702***   | 6.62      | -0.439***  | 6.41       |
| lnGDP      | -0.131***  | -3.10     | -0.149***  | -3.68     | -0.127***  | -3.29      |
| lnGDP2     | 1.218***   | 6.65      | 1.314***   | 6.75      | 1.611***   | 4.94       |
| lnEC       | 0.018***   | 3.23      | 0.022***   | 3.71      | 0.040***   | 3.14       |
| lnGC       | 0.094***   | 4.49      | 0.098***   | 4.55      | 0.063***   | 3.85       |
| lnQoG      | 0.081***   | 3.85      | 0.095***   | 4.50      | 0.076***   | 2.14       |
| lnKOF      | 0.068***   | 4.47      | 0.073***   | 4.81      | 0.058***   | 5.97       |

****statistics are given in parentheses. The symbols and indicate significance at 5% and 1% significance levels respectively.
Estimations of heterogeneous parameters

Now, the estimation of heterogeneous parameters can be implemented by CCEMG, AMG, and DCCE methods which are robust despite CD and slope heterogeneity (see Table 7).

In Table 7, it is highly notable that the signs and magnitudes of the long-run coefficients estimated by CCEMG, AMG, and DCCE methods are very similar. Also, all coefficients are statistically significant, which denotes the crucial impacts of lnGDP, lnGDP², lnEC, lnGC, lnQoG, lnKOF, and lnFD on CO2 emissions. The DCEE estimator shows that current CO2 emission negatively correlates with its lagged values in the long-run.

Energy consumption positively affects CO2 emissions. Namely, concerning the DCCE estimator, 1% increases in energy consumption causes 1.611% growth in CO2 emissions. The findings are consistent with the studies on energy consumption–CO2 emission relationships such as Pao and Tsai (2011) in BRICS, Rehman and Rashid (2017) in SAARC countries and Phong et al. (2018) in Vietnam. This signifies that energy consumption is an extremely important stimulation of CO2 in EMDEs, which can be explained by the high demand for energy of EMDEs in their industrialization processes. Besides, the utilization of old-fashioned technology in EMDEs, or the receipt of such technology from FDI fostered by their policies attracting foreign direct investment in all fields without consideration of environmental damage, presumably boosts CO2 emissions.

As regards the effect of GDP per capita on CO2 emissions, the coefficients of lnGDP and lnGDP² are positive and negative respectively, which indicates the inverted U-shaped relationship between economic growth and CO2 emissions. Thus, the EKC hypothesis is supported in the selected EMDEs. In the first stage of economic growth, pollution rises due to incremental economic activities. However, when the economy reaches a certain level, people focus more on the environmental quality and actively protect the environment by applying modern and energy-saving technology, use renewable energy,
and incorporate environment-friendly standards into foreign direct investment, which helps reduce CO₂ emissions. The findings are analogous to Ozturk and Acaravci (2013) in Turkey, Dogan and Seker (2016) for OECD countries, and Haseeb et al. (2018) for BRICS countries.

Globalization has positive impacts on CO₂ emissions and worsens environmental quality. It can be argued that the escalating pollution results from the role of globalization in lowering trade barriers and facilitating economic activities, thus degrading the environment. Also, the use of energy-hungry technology in the production processes of firms in EMDEs increases pollution level. The findings are in line with Latif et al. (2018) for BRICS, Shahbaz et al. (2018b) for 25 developing countries and Phong (2019) for ASEAN–5. Consequently, governments play important roles in improving economic conditions, exploiting the benefits of globalization, and sustainably protecting the environment.

Financial development also stimulates CO₂ emissions, which imply that the development of financial sectors of EMDEs possibly encourages new projects and activities but has not reached achievements in allocating finance for environment-friendly projects, thus boosting energy consumption and CO₂ emissions. Additionally, EMDEs have not utilized advanced and energy-saving technology in producing goods and services to attain low CO₂ emissions. The findings are not dissimilar to Tamazian and Rao (2010) in 24 transitional economies, Al-Mulali et al. (2015a) in 23 European countries, and Dar and Asif (2018b) in India.

Government expenditure raises CO₂ emissions in EMDEs, which is akin to Adewuyi (2016) in top 40 countries emitting CO₂, Yuelan et al. (2019) in China and Mohammed Saud et al. (2019) in Venezuela. The results in Table 7 also indicate that governance quality increases CO₂ emissions. This demonstrates that EMDEs face environmental degradation because they have relatively weak institution quality and environmental protection regulations (Ghosh 2010; Slesman et al. 2019). Obviously, there exist the scale effects of government expenditure and institution quality on EMDEs’ economic activities. It can be argued that the expansion of government expenditure and the improvement of institution quality can enhance economic activities and attract more trade and investment activities, which in turn amplify the scale effects on CO₂ emissions.

Results of panel causality tests

After estimating the long-run coefficients in the previous part, the author would like to examine the causation directions among variables. In order to guarantee the robustness, the author employs the D–H panel causality test of Dumitrescu and Hurlin (2012). It can be witnessed from Table 8 that all the null hypotheses of no causation are rejected as evidenced by extremely small p values. In other words, every causal direction is statistically significant below 1% level. The causality analysis affirms the existence of feedback effects in the connections between CO₂ emissions and other factors.

Conclusions and policy recommendations

The main objective of this study is to examine the relationships among globalization, financial development, government expenditure, institutional quality, energy consumption, economic growth, and CO₂ emissions in EMDEs, in conjunction with testing the EKC hypothesis. We detect cross-sectional dependence and slope heterogeneity in the panel data ranging from 1990 to 2014 and employ appropriate econometric methods to effectively deal with them. Accordingly, this paper uses CADF and CIPS unit root tests to verify the stationarity of the variables and finds that all variables are I(1). This necessitates Westerlund (2007) test to check for cointegration based on the error correction model, which confirms the long-run relationships among globalization, financial development, government expenditures, institutional quality, energy consumption, economic growth, and CO₂ emissions. Banerjee and Carrion-i-Silvestre (2017) cointegration test also denotes the stable long-term relationship among the selected variables. The heterogeneous parameters are evaluated by three econometric techniques including CCEMG, AMG, and DCCE estimators. The findings denote that globalization, financial development, government expenditure, institutional quality, energy consumption, and economic growth raise CO₂ emissions. The inverted U-shaped relationship between income level and CO₂ emissions (i.e., the EKC hypothesis) is acknowledged in EMDE countries. Besides, Dumitrescu and Hurlin causality analysis is utilized to test the causation among the variables and exhibits the feedback effects of the remaining variables on CO₂ emissions.

Surprisingly, globalization, financial development, government expenditure, and institutional quality boost pollution in EMDEs, which might be controversial. Nevertheless, this demonstrates that during the development process of EMDEs, there is a trade-off effect between economic growth and environmental quality. Obviously, the incremental government expenditure, financial development, or institutional quality enhancement can foster economic activities and perhaps attract more trade and investment activities through economic globalization, which in turn amplifies the scale effects of economic activities on CO₂ emissions. This result also implies that EMDE countries suffer from environmental degradation because they have relatively low financial development and weak institutional quality and environmental protection regulations (Ghosh, 2010; Slesman et al. 2019).

From the empirical findings of this paper, profound recommendations can be made for policy makers to consider the financial and governance roles of governments to guarantee the balance among energy consumption, financial
development, economic growth, and sustainable environmental quality in the globalization era. First, concerning energy consumption, the findings suggest that the governments of EMDE countries should have several environmental policies for sustainable development such as encourage efficient and effective energy use, upgrade old-fashioned technology towards modernity and efficiency, research and develop green, and renewable energy sources to reduce the impact of energy consumption on the environment. Second, although financial development is an integral part of financing industrialization and modernization processes, EMDE governments should further combine the concerns for environmental quality and financial reforming programs so as to protect the environment and maintain economic growth. Governments should also facilitate projects using efficient, green, and environment-friendly energy. Besides, due to the impact of globalization on the environment, this study adds a suggestion for policy makers that they should not ignore or underestimate the role of globalization in CO2 emissions. Rather, they are advised to treat globalization as an economic tool for designing comprehensive and sustainable environmental policy framework. Finally, the implementation of governmental activities via government expenditure and institutional reform in the past few years was presumably effective in terms of spillovers for activities in private sectors, enhanced trade and investment activities, which boosts economic growth in EMDE countries.

Notwithstanding, the findings of this study exhibit the trade-off effect between economic growth and environmental quality in EMDE countries. Hence, when the bases for economic growth are established, governments need to focus on the balance in economic growth and environment protection policies through their financial and governance activities. Also, governments should well ameliorate socio-economic circumstances, control corruption, implement strict environmental laws, balance environmental protection regulations with trade policies, and attract environmentally conscious investment to improve the environmental quality of EMDE countries.

Funding information This study has received funding from the European Union’s Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement no. 734712, and from the University of Economics Ho Chi Minh City, Vietnam.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

Table 9 Summary of some studies on EKC hypothesis

| Authors                | Period     | Countries                    | Variables          | Methodology         | EKC   |
|------------------------|------------|------------------------------|--------------------|---------------------|-------|
| Ang (2007)             | 1960–2000  | France                       | C; Y; Y²; E        | ARDL; Granger causality | Yes   |
| Apergis and Payne (2009) | 1971–2004  | 6 Central American countries | C; Y; Y²; E        | FOLS; VECM Granger causality | Yes   |
| Tamazian et al. (2009) | 1992–2004  | BRIC countries               | C; Y; Y²; IND; R&D; E; F | RE                | Yes   |
| Apergis and Payne (2010) | 1992–2004  | Commonwealth countries       | C; Y; Y²; E        | FOLS; VECM Granger causality | Yes   |
| Fodha and Zaghdoud (2010) | 1961–2004  | Tunisia                      | C/SO2; Y; Y²       | VECM Granger causality | Yes   |
| Lean and Smyth (2010)  | 1980–2006  | 5 ASEAN countries            | C; Y; Y²; E        | DOLS; VECM Granger causality | Yes   |
| Tamazian and Rao (2010) | 1993–2004  | 24 transitional economies    | C; Y; Y²; E; INF; FI; T; F; INS | RE; GMM  | Yes   |
| Jalil and Feridun (2011) | 1953–2006  | China                        | C; Y; Y²; E; T; F  | ARDL; VECM Granger causality | Yes   |
| Pao and Tsai (2011)    | 1971–2005  | BRICS                        | C; Y; Y²; E; FI    | OLS; VECM Granger causality | Yes   |
| Pao et al. (2011)      | 1990–2007  | Russia                       | C; Y; Y²; E        | OLS; VECM Granger causality | No    |
| Jayanthakumaran et al. (2012) | 1971–2007 | India and China              | C; Y; Y²; E; T    | ARDL                | Yes   |
| Saboori et al. (2012)  | 1980–2009  | Malaysia                     | C; Y; Y²          | ARDL; VECM Granger causality | Yes   |
| Ozcan (2013)           | 1990–2008  | 12 MENA countries            | C; Y; Y²; E        | FMOLS; VECM Granger causality | No    |
| Ozturk and Acaravci (2013) | 1960–2007 | Turkey                       | C; Y; Y²; E; T; F | ARDL               | Yes   |
| Shahbaz et al. (2013)  | 1970–2010  | Turkey                       | C; Y; Y²; E; KOF   | ARDL               | Yes   |
| Boutabba (2014)        | 1971–2008  | India                        | C; Y; Y²; T; FI    | ARDL; VECM Granger causality | Yes   |
| Farhani et al. (2014)  | 1971–2008  | Tunisia                      | C; Y; Y²; E; T    | ARDL; VECM Granger causality | Yes   |
## Table 9 (continued)

| Authors                  | Period      | Countries        | Variables | Methodology          | EKC |
|--------------------------|-------------|------------------|-----------|----------------------|-----|
| Shahbaz et al. (2014)    | 1971–2010   | Tunisia          | C; Y; Y²; E; T | ARDL; VECM Granger causality | Yes |
| Yavuz (2014)             | 1960–2007   | Turkey           | C; Y; Y²; E  | OLS; FMOLS            | Yes |
| Farhani and Ozturk (2015)| 1971–2012   | Tunisia          | C; Y; Y²; E; T; URB; F | ARDL; VECM Granger causality | No  |
| Shahbaz et al. (2015)    | 1970–2012   | India            | C; Y; Y²; E; KOF | ARDL; VECM Granger causality | Yes |
| Abid (2016)              | 1996–2010   | 25 SSA countries | C; Y; Y²; T; F; INS | OLS; GMM | No  |
| Dogan and Seker (2016)   | 1975–2011   | OECD             | C; Y; Y²; E; T; F | DSUR; E-K         | Yes |
| Dogan and Turkekul (2016)| 1960–2010   | US               | C; Y; Y²; E; T; URB; F | ARDL; VECM Granger causality | No  |
| Javid and Sharif (2016)  | 1972–2013   | Pakistan         | C; Y; Y²; E; T; F | ARDL; VECM Granger causality | Yes |
| Rehman and Rashid (2017) | 1960–2015   | SAARC countries  | C; Y; Y²; E; POG | FMOLS; DOLS; D-H Granger causality | Yes |
| Riti et al. (2017)       | 1970–2015   | China            | C; Y; Y²; E  | ARDL; FMOLS; DOLS; VECM Granger causality | Yes |
| Solarin et al. (2017)    | 1980–2012   | Ghana            | C; Y; Y²; E; INS; URB; T; F; F | ARDL | Yes |
| Zhang et al. (2017)      | 1971–2013   | NICs-10          | C; Y; Y²; E; T | OLS; FMOLS; DOLS     | Yes |
| Dar and Asif (2018a)     | 1960–2013   | Turkey           | C; Y; Y²; E; F | ARDL; H-J            | No  |
| Dar and Asif (2018b)     | 1971–2013   | India            | C; Y; Y²; E; F | ARDL; H-J            | No  |
| Farzanegan and Markwardt (2018) | 1980–2005 | 17 MENA countries | C;SO2; Y; Y²; T; URB; POD; L; EI; INS | OLS; GMM | Yes |
| Haseeb et al. (2018)     | 1995–2014   | BRICS countries  | C; Y; Y²; E; URB; F; KOF | DSUR; D-H Granger causality | Yes |
| Pata (2018)              | 1974–2013   | Turkey           | C; Y; Y²; PE; TE; URB; F; IND | ARDL | Yes |
| Phong et al. (2018)      | 1985–2015   | Vietnam          | C; Y; Y²; E; URB; KOF; IND | ARDL | Yes |
| Phong (2019)             | 1971–2014   | ASEAN-5          | C; Y; Y²; E; URB; F; KOF | FE; RE | Yes |
| Zafar et al. (2019)      | 1990–2014   | OECD             | C; Y; Y²; E; F; KOF | CUP-FM; CUP-BC | Yes |

**ARDL** autoregressive distributed lag, **C** carbon dioxide emissions, **CUP-BC** continuously updated bias-corrected, **CUP-FM** continuously updated fully modified ordinary least square, **D-H** Dumitrescu-Hurlin, **DOLS** dynamic ordinary least squares, **DSUR** dynamic seemingly unrelated regression, **E** energy consumption, **EI** energy intensity, **E-K** Emirmahmutoglu-Kose Granger causality, **FDI** foreign direct investment, **FE** fixed effects, **FMOLS** fully modified OLS, **GC** Granger causality, **GMM** generalized methods of moments, **H-J** Hatemi-J threshold cointegration technique, **IND** industrialization, **INF** inflation rate, **INS** institutions, **KOF** KOF globalization Index, **L** labor, **OLS** ordinary least squares, **POD** population density, **POG** population growth, **RE** random effects, **R&D** research development expenditure, **T** trade openness, **URB** urbanization, **VECM** vector error correction mechanism, **Y** income

## Table 10  List of countries

| No. | Country   | No. | Country    | No. | Country    | No. | Country   |
|-----|-----------|-----|------------|-----|------------|-----|-----------|
| 1   | Algeria   | 11  | Colombia   | 21  | Guatemala  | 31  | Mozambique|
| 2   | Argentina | 12  | Congo, Rep. | 22  | India      | 32  | Nicaragua |
| 3   | Bahrain   | 13  | Costa Rica | 23  | Indonesia  | 33  | Nigeria   |
| 4   | Bangladesh| 14  | Cote d’Ivoire | 24  | Iran, Islamic Rep. | 34  | Oman      |
| 5   | Bolivia   | 15  | Dominican Republic | 25  | Jordan     | 35  | Pakistan  |
| 6   | Botswana  | 16  | Ecuador    | 26  | Kenya      | 36  | Panama    |
| 7   | Brazil    | 17  | Egypt, Arab Rep. | 27  | Lebanon    | 37  | Paraguay  |
| 8   | Cameroon  | 18  | El Salvador | 28  | Malaysia   | 38  | Peru      |
| 9   | Chile     | 19  | Gabon      | 29  | Mexico     | 39  | Philippines |
| 10  | China     | 20  | Ghana      | 30  | Morocco    | 40  | Saudi Arabia |
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