

An investigation on the determinants of carbon emissions for OECD countries: empirical evidence from panel models robust to heterogeneity and cross-sectional dependence

Eyup Dogan¹ · Fahri Seker²

Received: 24 December 2015 / Accepted: 4 April 2016
© Springer-Verlag Berlin Heidelberg 2016

Abstract This empirical study analyzes the impacts of real income, energy consumption, financial development and trade openness on CO₂ emissions for the OECD countries in the Environmental Kuznets Curve (EKC) model by using panel econometric approaches that consider issues of heterogeneity and cross-sectional dependence. Results from the Pesaran CD test, the Pesaran-Yamagata's homogeneity test, the CADF and the CIPS unit root tests, the LM bootstrap cointegration test, the DSUR estimator, and the Emirmahmutoglu-Kose Granger causality test indicate that (i) the panel time-series data are heterogeneous and cross-sectionally dependent; (ii) CO₂ emissions, real income, the quadratic income, energy consumption, financial development and openness are integrated of order one; (iii) the analyzed data are cointegrated; (iv) the EKC hypothesis is validated for the OECD countries; (v) increases in openness and financial development mitigate the level of emissions whereas energy consumption contributes to carbon emissions; (vi) a variety of Granger causal relationship is detected among the analyzed variables; and (vii) empirical results and policy recommendations are accurate and efficient since panel econometric models used in this study account for heterogeneity and cross-sectional dependence in their estimation procedures.

Keywords Carbon emissions · EKC model · Heterogeneity · Cross-sectional dependence · OECD

Introduction

The last annual conference of the United Nations Framework Convention on Climate Change took place in Paris in November–December 2015.¹ As a result of extraordinary increases in environmental pollution and global warming, 196 nations that participated at the Paris meeting have agreed to keep the global warming below 2 °C above pre-industrial level. The achievement of this target requires continuous extreme declines in the level of greenhouse gas emissions. Because some of the largest emitters of greenhouse gases—the USA, India, Russian Federation, Japan and Canada—have not signed the second amendment of the Kyoto protocol which aims to decline the levels of world emissions through bindings for parties to the protocol,² it is for now doubtful whether or not the aforementioned largest emitters are going to ratify the Paris agreement. Nevertheless, given the fact that environmental pollution is currently a real and urgent concern to handle, researchers and policy makers from many countries are willing to know possible determinants of greenhouse gas emissions.

Studies including Soytaş et al. (2007), Lean and Smyth (2010), Yavuz (2014), Shahbaz et al. (2014), Dogan et al. (2015), Kasman and Duman (2015), Seker et al. (2015), Al-Mulali et al. (2015), Tang and Tan (2015), Farhani and Ozturk (2015), Dogan and Turkekul (2016), Javid and Sharif (2016),

Responsible editor: Philippe Garrigues

✉ Eyup Dogan
eyup.dogan@agu.edu.tr

Fahri Seker
fahri.fseker@gmail.com

¹ Department of Economics, Abdullah Gul University, Sumer Campus, Office #B211e, Kayseri, Turkey

² Department of Economics, Bozok University, Yozgat, Turkey

¹ <http://unfccc.int/resource/docs/2015/cop21/eng/109r01.pdf> (accessed 16 December 2015).

² http://unfccc.int/kyoto_protocol/doha_amendment/items/7362.php (accessed 16 December 2015).

and Zhang and Gao (2016) in the energy-environment-income literature show that energy consumption and real income are among the main determinants of carbon dioxide (CO₂) emissions for various nations and economic groups. In addition, Halicioglu (2009), Atici (2009), Jalil and Mahmud (2009), Jalil and Feridun (2011), Nasir and Rehman (2011), Shahbaz et al. (2014), Tang and Tan (2015), Seker et al. (2015), Javid and Sharif (2016), and Dogan and Seker (2016) indicate that financial development and trade openness can influence the level of emissions in a variety of countries and regions. Financial development, on the one hand, may increase energy consumption and carbon emissions due to increases in the purchase of new industrial machines and equipment caused by lower financing costs and increased financing networks; on the other hand, financial development may increase energy efficiency and efficiency of business performance resulting in lower energy consumption and CO₂ emissions (Dogan and Turkekul 2016). Increases in trade openness can impact carbon emissions through composition, scale, and technique effects (Farhani et al. 2014). More precisely, scale effect basically means that increases in trade may lead to higher production, higher energy consumption, and higher pollution. Composition effect implies that a country specializes in producing some goods with respect to the comparative advantage, and accordingly, increases in trade may lead to higher or lower pollution depending on whether goods that the country keeps producing are in energy-intensive sectors or not. Last, technique effect refers to technology spillover through trade flows among countries, and thus the adaptation of environmentally friendly technologies in producing goods can lead to environmental improvements. The aforementioned studies build on the Environmental Kuznets Curve (EKC) model wherein CO₂ emissions as proxy for greenhouse gas emissions are regressed on real income, the quadratic real income and energy consumption (and additional variables in some cases). The EKC hypothesis claims that increases in a country's real income lead to environmental improvements after the country passes threshold level.

Despite a large number of studies investigating the determinants of carbon emissions, those focusing on panel studies mostly use panel models that assume independent cross-sections and/or homogeneity. Relying on the assumptions of cross-sectional independence and homogeneity likely causes inefficient and inaccurate estimation results if the panel data are in fact heterogeneous and cross-sectionally dependent. Hence, we examine whether or not the panel data used in this study are homogenous and cross-sectionally independent, and indeed detect the issues of cross-sectional dependence and heterogeneity. We accordingly employ second-generation panel models (the CADF and the CIPS unit root tests, the LM bootstrap cointegration test, the dynamic seemingly unrelated cointegrating regressions (DSUR), and the Emirmahmutoglu-Kose Granger causality test) which take

into consideration both issues in their estimation procedures. Therefore, the reported results in this study are accurate, efficient, and robust.

The current empirical study contributes to the literature in several aspects as consistent with the abovementioned discussion. This study for the first time analyzes the influences of real income, energy consumption, financial development and trade openness on CO₂ emissions for the OECD countries in the EKC model by using recently developed panel approaches that deal with the issues of heterogeneity and cross-sectional dependence. The examination of the OECD countries is of interest to researchers and policy makers since this economic group is responsible for 72 % of 2013 world income (gross domestic product), 36 % of 2011 global carbon emissions, 40 % of 2011 energy consumption, and 69 % of 2013 world trade according to the World Development Indicators. In addition, it is a well-known financially developed economic group. Literature review is presented in the next section, model and data are described in the third section, methods, empirical results and policy recommendations are posted in fourth sections, and conclusions are given in the last section.

Literature review

The energy-environment-income literature includes a number of studies that investigate the presence of the EKC hypothesis and the influence of energy consumption, financial development, and trade for various single country and panel cases. The EKC hypothesis supported for single countries such as France (Ang 2007), China (Jalil and Mahmud 2009; Jalil and Feridun 2011), India (Jayanthakumaran et al. 2012; Tiwari et al. 2013), Pakistan (Nasir and Rehman 2011; Javid and Sharif 2016), Tunisia (Farhani et al. 2014; Shahbaz et al. 2014), Turkey (Ozturk and Acaravci 2013; Yavuz 2014; Seker et al. 2015; Gokmenoglu and Taspinar 2015; De-Vita et al. 2015), Malaysia (Lau et al. 2014; Saboori et al. 2012), Singapore (Katircioglu 2014), Iceland (Baek 2015), Vietnam (Tang and Tan 2015) as well as for panel studies such as 11 countries commonwealth of independent states (Apergis and Payne 2010), Central America (Apergis and Payne 2009), central and eastern European (Atici 2009), ASEAN (Lean and Smyth 2010), OECD (Cho et al. 2014), European countries (Kasman and Duman 2015), high-income countries (Al-Mulali et al. 2015), 14 Asian countries (Apergis and Ozturk 2015), BRICS (Pao and Tsai 2011), 34 developed and developing countries (Zaman et al. 2016), and top renewable energy countries (Dogan and Seker 2016). On the other hand, the hypothesis is not supported for the USA (Soytas et al. 2007; Baek 2015; Dogan and Turkekul 2016), Turkey (Halicioglu 2009), Russia (Pao et al. 2011), China (Du et al. 2012), Tunisia (Farhani and Ozturk 2015), Middle East countries (Ozcan 2013), and OECD countries (Dogan et al. 2015).

The contradiction across empirical results on the EKC hypothesis can occur because of the choice of country/region, time period and econometric approach.

The first group of studies focuses on single-country cases. They mostly use the ADF, the PP, and the KPSS unit root tests, the Johansen cointegration test, the bounds testing for cointegration, the ARDL model, and Granger causality based on the vector error correction mechanism (VECM). Energy consumption increases carbon emissions in Turkey (Say and Yucel 2006; Halicioglu 2009; Yavuz 2014; Seker et al. 2015), Vietnam (Tang and Tan 2015), the USA (Soytas et al. 2007; Dogan and Turkekul 2016), China (Jalil and Mahmud 2009; Jalil and Feridun 2011), the European Union (EU) members and candidate countries (Kasman and Duman 2015), Russia (Pao et al. 2011), Pakistan (Nasir and Rehman 2011; Javid and Sharif 2016), India (Jayanthakumaran et al. 2012), Malaysia (Shahbaz et al. 2013), Tunisia (Shahbaz et al. 2014; Farhani and Ozturk 2015), and Saudi Arabia (Alshehry and Belloumi 2015). In addition, Halicioglu (2009), Jalil and Feridun (2011), Nasir and Rehman (2011), Shahbaz et al. (2014), Farhani et al. (2014), and Farhani and Ozturk (2015) find that increases in trade lead to environmental degradation, whereas Jalil and Mahmud (2009), Jayanthakumaran et al. (2012), Shahbaz et al. (2013), Dogan and Turkekul (2016), and Javid and Sharif (2016) show that increases in trade lead to environmental improvements. Furthermore, Farhani and Ozturk (2015), Seker et al. (2015), and Javid and Sharif (2016) indicate that increases in financial development boost the pollution; on the contrary, Jalil and Feridun (2011), Shahbaz et al. (2013), and Tang and Tan (2015) suggest that a higher level of financial development reduces the level of emissions. Regarding causal relationship, one-way causality running from income to carbon emissions is found by Say and Yucel (2006), Alshehry and Belloumi (2015), Ang (2007), Nasir and Rehman (2011), Ajmi et al. (2015), and Seker et al. (2015); on the contrary, two-way Granger causality between carbon emissions and real income is found by Chandran and Tang (2013), Tang and Tan (2015), Shahbaz et al. (2013), Cowan et al. (2014), Pao et al. (2011), and Dogan and Turkekul (2016). In addition, one-way Granger causality from energy consumption to CO₂ is detected by Say and Yucel (2006), Soytas et al. (2007), and Cowan et al. (2014); on the contrary, two-way Granger causal relationship between energy consumption and emissions is supported by Pao et al. (2011), Javid and Sharif (2016), Tang and Tan (2015), Shahbaz et al. (2013), Dogan and Turkekul (2016), Nasir and Rehman (2011), and Zhang and Gao (2016). In addition, Farhani and Ozturk (2015) indicate that there is one-way causality running from CO₂ emissions to trade and from emissions to financial development. On the other hand, Seker et al. (2015), Gokmenoglu and Taspinar (2015), and Tang and Tan (2015) assert the presence of bidirectional Granger causality between financial development and pollution.

The second group focuses on panel studies. Apergis and Payne (2009) find that energy consumption stimulates carbon emissions, and one-way causality running from real income to emissions, from real income to energy consumption, two-way causality between energy consumption and CO₂ for Central American countries. Atici (2009) shows that increase in energy consumption boosts CO₂ emissions and the coefficient on trade is not statistically significant for central and eastern European countries. Hossain (2011) indicates that energy consumption and real income contribute to the level of emissions while trade mitigates it, and one-way Granger causality running from real income to emissions, from energy consumption to CO₂, and from trade to carbon emissions for newly industrialized countries. Pao and Tsai (2011) find that energy consumption and financial development contribute to pollution, and bidirectional Granger causality between real income and carbon emissions, between energy consumption and real income, between financial development and pollution, and one-way causality from energy consumption to the level of emissions for BRICS countries. Omri (2013) exhibits that energy consumption and real income contribute to the level of emissions, the coefficient on trade openness is insignificant, one-way Granger causality running from energy consumption to CO₂, and two-way Granger causality between real income and emissions for MENA countries. Kasman and Duman (2015) show that increases in trade and energy consumption lead to environmental degradation and bidirectional Granger causality between real income and emissions, between energy consumption and pollution, between openness and carbon emissions, and between energy consumption and real income for the EU members and candidate countries. Shahbaz et al. (2015) find that raises in real income and energy use stimulate pollution while higher levels of financial development lead environmental improvements, and that there is bidirectional Granger causality between financial development and carbon emissions, and between energy consumption and emissions for a panel of 99 countries. Al-Mulali et al. (2015) indicate that increases in trade openness and energy consumption contribute to environmental degradation, whereas financial development mitigates carbon emissions for a panel of 93 countries. Dogan et al. (2015) show that energy consumption stimulates the level of emissions while trade openness reduces pollution, and two-way Granger causality between CO₂ emissions and energy consumption, between emissions and real income, between energy consumption and real income, between trade and real income, and one-way causality running from trade openness to carbon emissions for the OECD countries. It is note-worthy that the mentioned studies use first-generation estimators (e.g., OLS and GMM) and first-generation Granger causality tests (e.g., pairwise and the VECM-based causality). The current study differs from the existing literature in that it uses a second-generation long-run estimator and a bootstrap Granger causality test.

Model and data description

The base EKC model wherein CO₂ emissions are regressed on income, quadratic income, and energy consumption is used by Soytaş et al. (2007), Apergis and Payne (2009), Pao et al. (2011), and Yavuz (2014). The base model can be shown as in Eq. 1:

$$\text{Model 1 : } \ln(\text{CO}_2)_{it} = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{it}^2 + \beta_3 \ln \text{EGY}_{it} + e_{it} \quad (1)$$

As discussed in the introduction section, financial development may influence the level of emissions through several channels. Thus, Pao and Tsai (2011), Seker et al. (2015), Dogan and Seker (2016), and Tang and Tan (2015) use the EKC model in Eq. 2:

$$\text{Model 2 : } \ln(\text{CO}_2)_{it} = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{it}^2 + \beta_3 \ln \text{EGY}_{it} + \beta_4 \ln \text{FD}_{it} + e_{it} \quad (2)$$

In addition to financial development, trade openness may determine environmental pollution through a number of effects. Therefore, Jalil and Mahmud (2009), Atici (2009), Nasir and Rehman (2011), Farhani et al. (2014), Shahbaz et al. (2014), and Dogan and Seker (2016) propose the EKC model in Eq. 3:

$$\text{Model 3 : } \ln(\text{CO}_2)_{it} = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{it}^2 + \beta_3 \ln \text{EGY}_{it} + \beta_4 \ln \text{TO}_{it} + e_{it} \quad (3)$$

As a combination of Eqs. 2 and 3, Jalil and Feridun (2011), and Javid and Sharif (2016) simultaneously estimate the influence of openness and financial development in the EKC model given in Eq. 4. This study also uses the following modified EKC model:

$$\text{Model 4 : } \ln(\text{CO}_2)_{it} = \beta_0 + \beta_1 \ln Y_{it} + \beta_2 \ln Y_{it}^2 + \beta_3 \ln \text{EGY}_{it} + \beta_4 \ln \text{FD}_{it} + \beta_5 \ln \text{TO}_{it} + e_{it} \quad (4)$$

wherein e_{it} error term; β_i are the coefficients on the explanatory variables. As regards to data selection, per capita CO₂ emissions are in metric tons; Y is real income (per capita GDP in 2005 US\$); EGY is per capita energy consumption in kilogram of oil equivalent; FD is financial development (the ratio of domestic credit to private sector as a share of Y); TO is trade openness (the ratio of the sum of exports and imports of goods and services as a share of Y). The data cover the period 1975–2011 and come from “the World Development Indicators” (<http://data.worldbank.org>) and are transformed into their natural logarithm so as to interpret the estimates as

the elasticities of the response variable (CO₂ emissions) with respect to the independent variables ($Y, Y^2, \text{EGY}, \text{FD}$ and TO). It is note-worthy that we optimize the data in that we employ the longest available data with the greatest number of cross-sections as possible. The sample OECD countries are Turkey, the USA, Greece, Japan, Australia, Finland, Sweden, Austria, Portugal, Belgium, Iceland, Denmark, Netherlands, France, the UK, and Spain. If the EKC hypothesis is valid, we will expect that $\beta_1 > 0$ and $\beta_2 < 0$. In addition, β_3 is expected to be positive, and the estimates of β_4 and β_5 can be greater or smaller than zero.

Methods and empirical results

The use of panel data has both advantages and disadvantages. In detail, panel models may suffer from the issues of heterogeneity and cross-sectional dependence whereas they are usually capable of capturing complexity of behavior of macroeconomic variables and include more degrees of freedom and more sample variation than single-country time-series data. On the other hand, recently developed econometric approaches take into consideration of both issues of cross-sectional dependence and heterogeneity, and therefore eliminate the mentioned drawbacks. We first investigate whether or not the panel data used in this study suffer from the mentioned issues and then use appropriate panel models accordingly.

Issues of heterogeneity and cross-sectional dependence

In order to detect whether or not slope coefficients are homogenous, we use the method of Pesaran and Yamagata (2008) that builds on the Swamy approach estimate the delta ($\tilde{\Delta}$) and the adjusted delta ($\tilde{\Delta}_{adj}$) so as to test null hypothesis of the slope homogeneity, $H_0: \beta_i = \beta$ for all individuals, against the alternative hypothesis of slope heterogeneity, $H_1: \beta_i \neq \beta_j$ for a non-zero fraction of pairwise slopes for $i \neq j$. This test has good small sample properties and can produce reliable results when T (time dimension) is greater than N (number of cross-sections). Referring to the computed $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$, results in Table 1 show that the null hypothesis of slope homogeneity can be rejected in favor of the alternative hypothesis of slope heterogeneity at 1 % level of significance. Given that heterogeneity exists across sample countries for the analyzed

Table 1 Results from heterogeneity tests

Test	lnY	lnY ²	lnEGY	lnFD	lnTO
$\tilde{\Delta}$	54.34*	54.62*	37.51*	29.56*	42.05*
$\tilde{\Delta}_{adj}$	56.25*	56.91*	39.08*	30.80*	43.81*

*Statistical significance at 1 % level

variables, we should employ heterogeneous panel techniques in which the parameters vary across cross sections.

In addition to heterogeneity, we apply the CD test developed by Pesaran (2004) to the analyzed variables to see whether or not each panel data is cross-sectionally independent. Results from the CD test are posted in Table 2. Referring to the associated *p* values, we can reject the null hypothesis of independent cross-sections in favor of the alternative of dependent cross-sections for the analyzed panel data.

Since the analyzed variables are not homogeneous and cross-sectionally independent, the first-generation tests likely produce inefficient results given that they have drawbacks of assuming cross-sectional independence and/or homogeneity. Phillips and Sul (2003) show that efficiency of estimation results may substantially decrease if cross-sectional dependence sufficiently exist across countries in the panel data and this is overlooked in estimation as it is commonly done by researchers. Henceforth, we should continue with second-generation panel models robust to both issues of cross-sectional dependence and heterogeneity so as to reveal efficient and accurate empirical results.

Panel unit root test

This study uses the CADF and CIPS unit root tests proposed by Pesaran (2007) to carry out integration properties of financial development, energy consumption, CO₂ emissions, real income, and trade openness. Because the CADF and CIPS tests produce accurate results in the presence of both heterogeneity and cross-sectional dependence, we prefer these second-generation unit root tests to first-generation ones such as LLC, IPS, and ADF unit root tests.

Results from the second-generation tests, the CADF and the CIPS, are reported in Table 3. Both tests indicate that carbon emissions, real income, energy consumption, financial development, and trade openness are not stationary at their levels but are stationary at their first differences. Therefore, the analyzed variables are integrated of order one, or equivalently, I (1). The panel data should be either stationary or cointegrated at their levels in order to assess statistically and economically meaningful long-run estimates of the independent variables. Because CO₂, Y, Y², EGY, FD, and TO are all I (1), this study applies a second-generation panel cointegration test to identify whether or not the analyzed panel data have a long-run relationship. Given that the mentioned panel

Table 2 Results from the CD-test

	lnCO ₂	lnY	lnY ²	lnEGY	lnFD	lnTO
CD test	7.55*	64.17 ^a *	64.18*	35.95*	34.86*	47.66*
<i>p</i> value	0.00	0.00	0.00	0.00	0.00	0.00

*Statistical significance at 1 % level

Table 3 Results from panel unit root tests

	CADF		CIPS	
	Level	Δ	Level	Δ
lnCO ₂	-2.34	-4.75*	-2.58	-5.95*
lnY	-2.27	-3.66*	-2.21	-4.41*
lnY ²	-2.23	-3.63*	-2.20	-4.38*
lnEGY	-2.27	-4.56*	-2.48	-6.08*
lnFD	-1.26	-3.54*	-1.27	-4.74*
lnTO	-2.47	-3.92*	-2.07	-5.06*

Δ denotes for the first differences

*Statistical significance at 1 % level

cointegration test requires the panel time series to be non-stationary at levels, the analyzed variables meet the necessary requirement.

Panel cointegration test

Despite the fact that the Pedroni, the Kao and the Johansen panel cointegration tests are commonly used in the literature, they have drawbacks of relying the assumption of cross-section dependence. Furthermore, failure to take into consideration of the issue of cross-section dependence causes loss of power in identifying the cointegration relationship among panel time-series data. Therefore, this study employs the LM bootstrap cointegration test considered as a second-generation cointegration test developed by Westerlund and Edgerton (2007) so as to check whether or not the level of emissions, real income, the quadratic real income, EGY, TO and FD are cointegrated. The bootstrap cointegration test take into consideration of both issues of dependent cross-sections and heterogeneity in identifying the cointegration relation among the variables, and thus is superior to the aforementioned first-generation cointegration tests. In addition, this test assumes the null hypothesis of cointegration.

Results from the bootstrap cointegration test are presented in Table 4. By referring to the bootstrap *p* value (0.98), we have no evidence to reject the null hypothesis of cointegration among CO₂ emissions, real income, the square of real income, energy consumption, financial development and trade openness for the OECD countries. We can confidently conclude that the analyzed variables have a long-run relationship. More

Table 4 Results from panel cointegration test

Test	LM statistic	Bootstrap <i>p</i> value
LM bootstrap cointegration	11.91	0.98

The bootstrap test is computed by stochastic simulations using 5000 replications

importantly, the finding of cointegration relationship among CO₂, Y, Y², EGY, FD and TO is efficient, robust, and accurate since the LM cointegration test handle the issues of dependent cross-sections and heterogeneity in the estimation procedure.

Long-run estimates

An important inference of an empirical study is to estimate long-run coefficients on the explanatory variables (Y, Y², EGY, FD, TO) once one confirms that the level of emissions, real income, the quadratic real income, trade openness, energy consumption and financial development has a long-run relationship. Nearly all studies in the literature use either the ordinary least squares estimates (OLS) or the dynamic OLS (DOLS) and/or the fully modified OLS (FMOLS); however, they may fail to produce efficient and accurate long-run coefficient estimates since the aforementioned estimators rely on the assumption of independent cross-sections. In addition to testing cross-sectional independence and homogeneity for individual panel time-series data reported in Tables 1 and 2, we also investigate the issues of cross-sectional dependence and heterogeneity for model 4, $f(\text{CO}_2|Y, Y^2, \text{EGY}, \text{FD}, \text{TO})$, by using Pesaran's CD test and the method of Pesaran and Yamagata (2008). Results reported in Table 5 indicate that we have enough evidence to reject the null hypothesis of homogeneity and the null hypothesis of independent cross-sections, which support country-specific heterogeneity and cross-sectional dependence for sample countries for the proposed model 4.

Given the presence of the issues of cross-sectional dependence and heterogeneity in panel data, we should use a second-generation estimator that takes into account the mentioned issues rather than the DOLS and the FMOLS. Hence, this study employs a second-generation long-run estimator, namely the dynamic seemingly unrelated cointegrating regressions (DSUR) due to Mark et al. (2005). In case that, T is relatively greater than N ; the DSUR estimator can still be a good and useful predictor with consistent and asymptotically normal distribution. Results from the DSUR estimator are posted in Table 6.

Table 5 Results from cross-sectional independence and homogeneity tests

Test	Statistic	<i>p</i> value
CD test (Pesaran 2004)	6.73*	0.00
$\tilde{\Delta}$ (Pesaran and Yamagata 2008)	24.66*	0.00
$\tilde{\Delta}_{adj}$ (Pesaran and Yamagata 2008)	26.87*	0.00

These tests are for model 4, $f(\text{CO}_2|Y, Y^2, \text{EGY}, \text{FD}, \text{TO})$

*Statistical significance at 1 % level

Table 6 Results from the panel DSUR

Regressors	Coefficient	<i>t</i> -statistic	<i>p</i> value
lnY	4.48*	89.61	0.00
lnY ²	-0.22*	-11.30	0.00
lnEGY	0.66*	22.06	0.00
lnFD	-0.04*	-44.10	0.00
lnTO	-0.02*	-11.00	0.00

The dependent variable is CO₂

*Statistical significance at 1 % level

The reported coefficients in Table 6 are statistically significant at 1 % level. Because the panel data are transformed into their natural logarithm, the coefficients on Y, Y², EGY, FD and TO are equal to the elasticities of carbon emissions with respect to real income, the square of real income, energy consumption, financial development, and trade openness, respectively. Regarding real income, it is found that the signs of the coefficient estimates of real income and the quadratic real income are positive (+4.48) and negative (-0.22), respectively. More precisely, the (partial) marginal effect of real income on carbon emissions is computed by $\beta_1 + 2\beta_2 * Y$, indicating that the (partial) marginal effect of real income on the level of emissions is clearly positive for the group of low-income OECD countries, but it decreases and eventually becomes negative as they shift to the group of high-income countries. In other words, increases in real income leads to environmental improvements as the OECD countries pass the threshold income level. This conclusion supports the existence of the EKC hypothesis for the sample OECD countries. It is consistent with Apergis and Payne (2009), Atici (2009), Lean and Smyth (2010), Pao and Tsai (2011), Nasir and Rehman (2011), Jalil and Feridun (2011), Saboori et al. (2012), Shahbaz et al. (2014), Yavuz (2014), Lau et al. (2014), Al-Mulali et al. (2015), Kasman and Duman (2015), Seker et al. (2015), Tang and Tan (2015), Javid and Sharif (2016), Dogan and Seker (2016) and Zaman et al. (2016). In addition, we find that the threshold level of per capita income equals to approximately \$26,500 given that the turning point is calculated by $\exp(-4.48/2*0.22)$. The turning point is found \$1785 for a panel of Central America countries (Apergis and Payne 2009), \$2320 for a panel of ASEAN countries (Lean and Smyth 2010), \$625 for Pakistan (Nasir and Rehman 2011), \$4700 for Malaysia (Saboori et al. 2012), \$2100 for Tunisia (Shahbaz et al. 2014), \$5150 for Turkey (Seker et al. 2015), \$4000 for a panel of the EU members and candidate countries (Kasman and Duman 2015), and \$59,000 for a panel of OECD countries (Jebli et al. 2016). The turning point substantially varies across countries and panels.

Regarding the influence of energy consumption on carbon emissions in the OECD countries, a 1 % increase in energy consumption boosts the level of emissions 0.66 %. As sample

countries consume more energy, they also produce more carbon emissions. The positive coefficient on energy consumption for CO₂ emissions is in line with Say and Yucel (2006), Ang (2007), Soytaş et al. (2007), Apergis and Payne (2009), Atici (2009), Halicioglu (2009), Lean and Smyth (2010), Acaravci and Ozturk (2010), Pao et al. (2011), Pao and Tsai (2011), Hossain (2011), Nasir and Rehman (2011), Jalil and Feridun (2011), Alam et al. (2012), Park and Hong (2013), Omri (2013), Shahbaz et al. (2013), Lau et al. (2014), Shahbaz et al. (2014), Farhani et al. (2014), Yavuz (2014), Kasman and Duman (2015), Dogan et al. (2015), Baek (2015), Seker et al. (2015), Al-Mulali et al. (2015), Shahbaz et al. (2015), Tang and Tan (2015), Farhani and Ozturk (2015), Dogan and Turkecul (2016), Javid and Sharif (2016), and Zhang and Gao (2016). The OECD countries are advised to increase the level of energy efficiency as well as increase the share of renewable sources in energy mix referring to Shafiei and Salim (2014) and Jebli et al. (2016) who find that increases in renewable energy consumption lessen the level of emissions whereas increases in non-renewable energy consumption stimulate carbon emissions in the OECD countries. Therefore, the OECD countries should pay more attention on the development of methods for increased energy efficiency, renewable energy, and environmental protection.

The elasticity of CO₂ emissions with respect to financial development is -0.04 . It indicates that increases in financial development in the OECD countries mitigate the level of emissions. This finding is consistent with that of Jalil and Feridun (2011), Shahbaz et al. (2013), Tang and Tan (2015), Shahbaz et al. (2015), and Al-Mulali et al. (2015). The coefficient estimate of trade openness for carbon emissions is -0.02 . In words, a 1 % rise in trade openness lowers the levels of carbon emissions by 0.02 % for the OECD countries. The adverse influence of trade openness is line with Jalil and Mahmud (2009), Hossain (2011), Jayanthakumaran et al. (2012), Shahbaz et al. (2013), Dogan and Turkecul (2016), Jebli et al. (2016), and Javid and Sharif (2016). It seems that technique and composition effects of trade openness dominate the scale effect, and the OECD countries specialize in the production of non-energy intensive goods and services. The OECD members likely take advantages of technology spillover through trade and financial development. In addition, energy intensive and dirty industries operated in the OECD countries seem to prefer to move to developing and undeveloped countries wherein relatively less environmental standards are regulated. The latter case mainly refers to the pollution-haven hypothesis which asserts that the developed countries with public awareness of environmental pollution make dirty factories to relocate and operate in countries with lower environmental regulations and enforcements (Cole 2004). This study thus suggests that the OECD countries should support increased trade openness and financial development, and should keep forcing dirty industries by

environmental regulations to move to other countries or to use environmentally friendly technologies in their production processes.

Panel Granger causality test

The coefficients obtained from the DSUR estimator undoubtedly offer significant inferences but do not reveal the direction of Granger causality among the analyzed variables. Notwithstanding, it is also of interest for researchers to find out information regarding the causal relationship between carbon emissions, real income, energy consumption, financial development and trade openness. Rather than first-generation panel Granger causality techniques (e.g., pairwise and the VECM Granger causality tests), we use the bootstrap panel Granger causality test developed by Emirmahmutoglu and Kose (2011) accounting for both issues of heterogeneity and cross-sectional dependence in panels.

Results from the bootstrap panel Granger causality test due to Emirmahmutoglu and Kose (2011) are reported in Table 7. We have enough evidence to conclude that there is bidirectional causality between CO₂ emissions and energy consumption, the levels of emissions and trade openness, real income and financial development, the square of real income and financial development, real income and trade openness, quadratic real income and trade openness, energy consumption and financial development, and energy consumption and trade openness. In addition, empirical findings support one-way Granger causality running from real income to CO₂ emissions, from the square of real income to pollution, from energy consumption to real income, from energy consumption to quadratic real income and from financial development to trade openness. The outcomes are consistent with Soytaş et al. (2007), Ang (2007), Halicioglu (2009), Apergis and Payne (2009), Nasir and Rehman (2011), Hossain (2011), Chandran and Tang (2013), Shahbaz et al. (2013), Dogan (2014), Cowan et al. (2014), Ajmi et al. (2015), Alshehry and Belloumi (2015), Kasman and Duman (2015), Ucak et al. (2015), Shahbaz et al. (2015), Seker et al. (2015), Tang and Tan (2015), Dogan and Turkecul (2016), and Zhang and Gao (2016).

The overall conclusion that we reach on causal relationship among CO₂ emissions, real income, energy consumption, financial development and trade openness is also consistent with the findings that we obtain in the previous section. In detail, real income, energy consumption, financial development, and trade openness determine the level of emissions. In addition, carbon emissions also Granger cause financial development, trade openness and energy consumption, likely indicating that increases in pollution lead the OECD countries to encourage and support trade and financial development as well as to focus and invest on environmentally friendly energy. Furthermore, the sample countries face a tradeoff between

Table 7 Results from the Emirmahmutoglu-Kose Granger causality test

Hypothesis	Fisher statistic	<i>p</i> value	Conclusion
$\ln Y \rightarrow \ln CO_2$	50.22**	0.02	One-way causality from $\ln Y$ to $\ln CO_2$
$\ln CO_2 \rightarrow \ln Y$	38.71	0.19	
$\ln Y^2 \rightarrow \ln CO_2$	50.24**	0.02	One-way causality from $\ln Y^2$ to $\ln CO_2$
$\ln CO_2 \rightarrow \ln Y^2$	37.57	0.22	
$\ln EGY \rightarrow \ln CO_2$	42.38*	0.10	Two-way causality between $\ln EGY$ and $\ln CO_2$
$\ln CO_2 \rightarrow \ln EGY$	54.60***	0.00	
$\ln FD \rightarrow \ln CO_2$	42.49*	0.10	One-way causality from $\ln FD$ to $\ln CO_2$
$\ln CO_2 \rightarrow \ln FD$	27.19	0.71	
$\ln TO \rightarrow \ln CO_2$	58.10***	0.00	Two-way causality between $\ln CO_2$ and $\ln TO$
$\ln CO_2 \rightarrow \ln TO$	46.97**	0.04	
$\ln EGY \rightarrow \ln Y$	50.21**	0.02	One-way causality from $\ln EGY$ to $\ln Y$
$\ln Y \rightarrow \ln EGY$	37.97	0.21	
$\ln EGY \rightarrow \ln Y^2$	50.46**	0.02	One-way causality from $\ln EGY$ to $\ln Y^2$
$\ln Y^2 \rightarrow \ln EGY$	38.00	0.21	
$\ln FD \rightarrow \ln Y$	85.86***	0.00	Two-way causality between $\ln FD$ and $\ln Y$
$\ln Y \rightarrow \ln FD$	58.39***	0.00	
$\ln FD \rightarrow \ln Y^2$	86.34***	0.00	Two-way causality between $\ln FD$ and $\ln Y^2$
$\ln Y^2 \rightarrow \ln FD$	59.02***	0.00	
$\ln TO \rightarrow \ln Y$	47.71**	0.03	Two-way causality between $\ln TO$ and $\ln Y$
$\ln Y \rightarrow \ln TO$	59.13***	0.00	
$\ln TO \rightarrow \ln Y^2$	47.83**	0.03	Two-way causality between $\ln TO$ to $\ln Y^2$
$\ln Y^2 \rightarrow \ln TO$	59.41***	0.00	
$\ln EGY \rightarrow \ln FD$	43.39*	0.08	Two-way causality between $\ln FD$ and $\ln Y$
$\ln FD \rightarrow \ln EGY$	57.99***	0.00	
$\ln EGY \rightarrow \ln TO$	45.18*	0.06	Two-way causality between $\ln TO$ to $\ln EGY$
$\ln TO \rightarrow \ln EGY$	56.67***	0.00	
$\ln FD \rightarrow \ln TO$	45.97**	0.05	One-way causality from $\ln FD$ to $\ln TO$
$\ln TO \rightarrow \ln FD$	28.47	0.64	

***, **, *Statistical significance at 1 % level, 5 % level, and 10 % level, respectively

decreasing energy consumption for lower pollution and increasing energy consumption for higher real income since both energy-led-pollution and energy-led-income hypotheses are supported. Thus, regulatory policies should be carefully implemented considering the mentioned dilemma. Last, this study supports feedback hypothesis between real income and trade openness, and between real income and financial development. This implies that increases in trade and financial development not only directly but also indirectly (through real income) mitigate the level emissions since the EKC hypothesis is valid for the OECD countries. Hence, the governments should impose necessary policies to stimulate trade and financial development for lower levels of pollution and higher levels of real income.

Conclusions and policy implications

The last conference on the climate change with the participation of more than 190 nations was held in Paris in November–December 2015. Because the achievement of targeted global warming by 2100 requires continued reductions in greenhouse

gas emissions, it becomes a globally hot topic to investigate and expose the long-run determinants of the level of emissions. In consistent with the recent global trend, this empirical research aims to analyze the influence of real income, the quadratic real income, energy consumption, financial development, and trade openness on CO₂ emissions for the OECD countries in the well-known EKC model. Because the OECD accounts for a large part of worldwide carbon emissions, real income (gross domestic product), energy consumption, and trade and financial activities, the empirical results obtained in this study are of essential guidance to governments in shaping environmental regulations and policies.

The DSUR estimator reports that financial development and trade openness decrease carbon emissions; on the other hand, energy consumption contributes to the level of emissions. The validity of the EKC hypothesis is supported for the OECD countries, implying that as the OECD countries reach and pass the threshold income level, increases in real income lead to environmental improvements. The Emirmahmutoglu-Kose Granger causality show the existence of two-way Granger causality between CO₂ and energy consumption, and between emissions and trade openness, and the

presence of one-way Granger causality running from real income to CO₂ emissions, from energy consumption to real income. In order to reduce the level of emissions, the OECD countries are advised to increase energy efficiency, stimulate trade and financial development through encouragement acts, force dirty and energy-intensive firms by strict environmental regulations to move to other countries with less environmental laws, support scientific intuitions to develop more energy efficient machines used in production processes, and increase the public awareness of environmental protection. The policy implications discussed in this study are robust and accurate since we use panel models that account for generally overlooked issues of cross-sectional dependence and heterogeneity.

References

- Acaravci A, Ozturk I (2010) On the relationship between energy consumption, CO₂ emissions and economic growth in Europe. *Energy* 35(12):5412–5420
- Ajmi AN, Hammoudeh S, Nguyen DK, Sato JR (2015) On the relationships between CO₂ emissions, energy consumption and income: the importance of time variation. *Energy Econ* 49:629–638
- Alam MJ, Begum IA, Buysse J, Van Huylenbroeck G (2012) Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. *Energy Policy* 45:217–225
- Al-Mulali U, Weng-Wai C, Sheau-Ting L, Mohammed AH (2015) Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. *Ecol Indic* 48:315–323
- Alshehry AS, Belloumi M (2015) Energy consumption, carbon dioxide emissions and economic growth: the case of Saudi Arabia. *Renew Sust Energ Rev* 41:237–247
- Ang JB (2007) CO₂ emissions, energy consumption, and output in France. *Energy Policy* 35(10):4772–4778
- Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. *Ecol Indic* 52:16–22
- Apergis N, Payne JE (2009) CO₂ emissions, energy usage, and output in Central America. *Energy Policy* 37(8):3282–3286
- Apergis N, Payne JE (2010) The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states. *Energy Policy* 38(1):650–655
- Atici C (2009) Carbon emissions in central and eastern Europe: environmental Kuznets curve and implications for sustainable development. *Sustain Dev* 17(3):155–160
- Baek J (2015) Environmental Kuznets curve for CO₂ emissions: the case of Arctic countries. *Energy Econ* 50:13–17
- Chandran VGR, Tang CF (2013) The impacts of transport energy consumption, foreign direct investment and income on CO₂ emissions in ASEAN-5 economies. *Renew Sust Energ Rev* 24:445–453
- Cho CH, Chu YP, Yang HY (2014) An environment Kuznets curve for GHG emissions: a panel cointegration analysis. *Energy Sources Part B Econ Plan Policy* 9(2):120–129
- Cole MA (2004) Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. *Ecol Econ* 48(1):71–81
- Cowan WN, Chang T, Inglesi-Lotz R, Gupta R (2014) The nexus of electricity consumption, economic growth and CO₂ emissions in the BRICS countries. *Energy Policy* 66:359–368
- De-Vita G, Katircioglu S, Altinay L, Fethi S, Mercan M (2015) Revisiting the environmental Kuznets curve hypothesis in a tourism development context. *Environ Sci Pollut Res* 22(21):16652–16663
- Dogan E (2014) Energy consumption and economic growth: evidence from low-income countries in Sub-Saharan Africa. *Int J Energy Econ Policy* 4(2):154–162
- Dogan E, Seker F (2016) The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. *Renew Sust Energ Rev* 60:1074–1085
- Dogan E, Turkekul B (2016) CO₂ emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environ Sci Pollut Res* 23(2):1203–1213
- Dogan E, Seker F, Bulbul S (2015). Investigating the impacts of energy consumption, real GDP, tourism and trade on CO₂ emissions by accounting for cross-sectional dependence: a panel study of OECD countries. *Curr Issues Tour* 1–19
- Du L, Wei C, Cai S (2012) Economic development and carbon dioxide emissions in China: provincial panel data analysis. *China Econ Rev* 23(2):371–384
- Emirmahmutoglu F, Kose N (2011) Testing for Granger causality in heterogeneous mixed panels. *Econ Model* 28(3):870–876
- Farhani S, Ozturk I (2015) Causal relationship between CO₂ emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. *Environ Sci Pollut Res* 22(20):15663–15676
- Farhani S, Chaibi A, Rault C (2014) CO₂ emissions, output, energy consumption, and trade in Tunisia. *Econ Model* 38:426–434
- Gokmenoglu K, Taspinar N (2015) The relationship between CO₂ emissions, energy consumption, economic growth and FDI: the case of Turkey. *J Int Trade Econ Dev* 1–18
- Halicoglu F (2009) An econometric study of CO₂ emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy* 37(3):1156–1164
- Hossain MS (2011) Panel estimation for CO₂ emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* 39(11):6991–6999
- Jalil A, Feridun M (2011) The impact of growth, energy and financial development on the environment in China: a cointegration analysis. *Energy Econ* 33(2):284–291
- Jalil A, Mahmud SF (2009) Environment Kuznets curve for CO₂ emissions: a cointegration analysis for China. *Energy Policy* 37(12):5167–5172
- Javid M, Sharif F (2016) Environmental Kuznets curve and financial development in Pakistan. *Renew Sust Energ Rev* 54:406–414
- Jayanthakumaran K, Verma R, Liu Y (2012) CO₂ emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy* 42:450–460
- Jebli MB, Youssef SB, Ozturk I (2016) Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecol Indic* 60:824–831
- Kasman A, Duman YS (2015) CO₂ emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. *Econ Model* 44:97–103
- Katircioglu ST (2014) Testing the tourism-induced EKC hypothesis: the case of Singapore. *Econ Model* 41:383–391
- Lau LS, Choong CK, Eng YK (2014) Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter? *Energy Policy* 68:490–497
- Lean HH, Smyth R (2010) CO₂ emissions, electricity consumption and output in ASEAN. *Appl Energy* 87(6):1858–1864

- Mark NC, Ogaki M, Sul D (2005) Dynamic seemingly unrelated cointegrating regressions. *Rev Econ Stud* 72(3):797–820
- Nasir M, Rehman FU (2011) Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. *Energy Policy* 39(3):1857–1864
- Omri A (2013) CO₂ emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models. *Energy Econ* 40:657–664
- Ozcan B (2013) The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: a panel data analysis. *Energy Policy* 62:1138–1147
- Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Econ* 36:262–267
- Pao HT, Tsai CM (2011) Multivariate Granger causality between CO₂ emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy* 36(1):685–693
- Pao HT, Yu HC, Yang YH (2011) Modeling the CO₂ emissions, energy use, and economic growth in Russia. *Energy* 36(8):5094–5100
- Park J, Hong T (2013) Analysis of South Korea's economic growth, carbon dioxide emission, and energy consumption using the Markov switching model. *Renew Sust Energy Rev* 18:543–551
- Pesaran MH (2004) General diagnostic tests for cross section dependence in panels. Working Papers in Economics No. 0435. University of Cambridge, Cambridge
- Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. *J Appl Econ* 22(2):265–312
- Pesaran MH, Yamagata T (2008) Testing slope homogeneity in large panels. *J Econ* 142(1):50–93
- Phillips P, Sul D (2003) Dynamic panel estimation and homogeneity testing under cross section dependence. *Econ J* 6(1):217–259
- Saboori B, Sulaiman J, Mohd S (2012) Economic growth and CO₂ emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. *Energy Policy* 51:184–191
- Say NP, Yucel M (2006) Energy consumption and CO₂ emissions in Turkey: empirical analysis and future projection based on an economic growth. *Energy Policy* 34(18):3870–3876
- Seker F, Ertugrul HM, Cetin M (2015) The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey. *Renew Sust Energy Rev* 52:347–356
- Shafiei S, Salim RA (2014) Non-renewable and renewable energy consumption and CO₂ emissions in OECD countries: a comparative analysis. *Energy Policy* 66:547–556
- Shahbaz M, Solarin SA, Mahmood H, Arouri M (2013) Does financial development reduce CO₂ emissions in Malaysian economy? A time series analysis. *Econ Model* 35:145–152
- Shahbaz M, Khraief N, Uddin GS, Ozturk I (2014) Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia. *Renew Sust Energy Rev* 34:325–336
- Shahbaz M, Nasreen S, Abbas F, Anis O (2015) Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? *Energy Econ* 51:275–287
- Soytas U, Sari R, Ewing BT (2007) Energy consumption, income, and carbon emissions in the United States. *Ecol Econ* 62(3):482–489
- Tang CF, Tan BW (2015) The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy* 79:447–454
- Tiwari AK, Shahbaz M, Hye QMA (2013) The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. *Renew Sust Energy Rev* 18:519–527
- Ucak H, Aslan A, Yucel F, Turgut A (2015) A dynamic analysis of CO₂ emissions and the GDP relationship: empirical evidence from high-income OECD countries. *Energy Sources Part B Econ Plan Policy* 10(1):38–50
- Westerlund J, Edgerton DL (2007) A panel bootstrap cointegration test. *Econ Lett* 97:185–190
- Yavuz NC (2014) CO₂ emission, energy consumption, and economic growth for turkey: evidence from a cointegration test with a structural break. *Energy Sources Part B Econ Plan Policy* 9(3):229–235
- Zaman K, Shahbaz M, Loganathan N, Raza SA (2016) Tourism development, energy consumption and environmental Kuznets curve: trivariate analysis in the panel of developed and developing countries. *Tour Manag* 54:275–283
- Zhang L, Gao J (2016) Exploring the effects of international tourism on China's economic growth, energy consumption and environmental pollution: evidence from a regional panel analysis. *Renew Sust Energy Rev* 53:225–234