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RESEARCH ARTICLE

# Does economic complexity matter for environmental degradation? An empirical analysis for different stages of development

Buhari Doğan[1] · Behnaz Saboori[2] · Muhlis Can[3]

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## Abstract

This study is among the first attempts to examine the effect of economic complexity as an indicator of sophisticated and knowledge-based production structures on $CO_2$ emissions for 55 countries over the period of 1971–2014. The countries considered fall into three different income groups, namely high income, higher middle income, and lower middle income. The study employs the panel quantile regression methodology and tests the existence of the environmental Kuznets curve (EKC) hypothesis by including economic complexity and other control variables such as energy consumption, urbanization, and trade openness in its model. The results show that economic complexity has significant impacts on the environment. Based on the analysis, economic complexity has increased the environmental degradation in lower and higher middle-income countries, and has controlled $CO_2$ emissions in high-income countries. Since economic complexity plays a significant role in environmental damage, it is crucial for low- and middle-income countries to adjust their current industrial and production policies to promote economic growth and at the same time protect the environment.

**Keywords** Economic complexity · $CO_2$ emissions · Panel quantile regression · Environmental Kuznets curve

## Introduction

Global warming is the greatest environmental threat that countries have ever faced. Countries' economic growth effort is the most significant source of this problem. The economic growth efforts of countries that have constantly continued at full speed will lead to more energy consumption (Gozgor and Can 2017a). The energy demand in the world increased by an average of 2.4 % between 1850 and 2010 (Jarvis et al. 2012). Environmental problems have increased as a result of increasing energy consumption (Gozgor and Can 2017b and Fang et al. 2019). According to a report by the International Energy Agency (IEA), atmospheric $CO_2$ has increased by 40 % compared to the eighteenth century (IEA 2013). For this reason, policymakers aim to sustain economic growth and development while trying to reduce the negative environmental impacts of energy consumption (Saboori and Sulaiman 2013). In this context, the environmental Kuznets curve (EKC) hypothesis, which examines the relationship between economic growth and environmental degradation, is employed. According to this hypothesis, environmental degradation increases until the country reaches a certain level of income. After a turning point, environmental degradation is expected to decrease with the increase in income. In other words, there is an "inverse *U*" relationship between income and environmental degradation (Katircioglu et al. 2018).

After the study by Grossman and Krueger (1995), many scholars have tested the existence of the EKC for different countries or country groups. Some studies have highlighted the importance of economic growth as an important source of environmental degradation on the basis of the EKC hypothesis (Grossman and Krueger 1995; Farhani and Rejeb 2012; Shuai et al. 2017; Śmiech and Papież 2014 and Orubu and Omotor

Responsible editor: Philippe Garrigues

Behnaz Saboori
behnazsaboori@yahoo.com

Buhari Doğan
doganbuhari@gmail.com

Muhlis Can
muhliscan@yandex.com

1 Suleyman Demirel University, Isparta, Turkey

2 Faculty of Economics and Accounting, South Tehran Branch, Islamic Azad University, Tehran, Iran

3 Hakkari University, Hakkâri, Turkey

2011). Moreover, some scholars have included various explanatory variables in the EKC model, such as employment, financial development, population, tourism, foreign direct investments, trade openness, technology, and urbanization (e.g., Ahmed et al. 2016; Al-mulali et al. 2015; Al-mulali and Ozturk 2016; Apergis and Ozturk 2015, b; Aye and Edoja 2017; Balin and Akan 2015; De Vita et al. 2015; Dogan and Seker 2016, Gaspar et al. 2017; Hill and Magnani 2002; Ibrahim and Law 2015; Lee and Brahmasrene 2013; Sulaiman et al. 2013; Kasman and Duman 2015; Katircioglu 2014a; Katircioglu 2014b; Katircioglu and Katircioglu 2018a; Katircioglu and Katircioglu 2018b; Luo et al. 2017; Mensah et al. 2018; Paramati et al. 2016; Pao and Tsai 2011; Pazienza 2015; Shafiei and Salim 2014; Sinha and Sen 2016; Sinha et.al. 2017; Zaman et al. 2016;Zhang et al. 2017 and Rasoulinezhad and Saboori 2018). However, it is observed that, despite the importance of countries' economic structure (agricultural, industrial, or technological) to environmental performance, this factor is ignored in the literature.

Thus, this study is one of the first attempts to investigate the effect of economic complexity as a measure of a country's sophisticated and knowledge-based production structure (economic structure) on the environment over the period of 1971–2014. The study considers 55 countries with different income levels. This study contributes to previous literature on the following three fronts. First, according to our best knowledge, this is the first study that investigates the effects of economic complexity on $CO_2$ emissions in 55 countries at different stages of development and income including (lower middle income, higher middle income, and high income). Second, the study tests not only the effect of economic complexity but also the effects of other explanatory variables such as trade openness and urbanization, on environmental degradation in the same model. Finally, the study employs quantile regression fixed-effects models to estimate the effect of economic complexity and other explanatory variables on $CO_2$ emissions.

The rest of the paper is organized as follows. "Literature review" provides the literature review, "Data, empirical model, and econometric methodology" introduces the model and adopted methodology, "Empirical results" reports the findings, and "Conclusion and policy implications" concludes the paper and outlines its policy implications.

## Literature review

Theoretically, environmental degradation is minimal in the first phase of development, in which countries specialize in agricultural-based products. Gradually, countries move from agricultural products to industrial manufacturing (Dinda 2004). During this stage, the environmental sensitivity is very low and the production of pollution-intensive products is increasing. As a result, the country consumes more energy, which is harmful to the environment (Gozgor and Can 2016). After a certain level of income,[1] the country moves towards more on technologically based production. With an increase in income, the environmental sensitivity of the society increases and the country ends production of pollution-emitting products. Therefore, countries will direct their production factors to the groups of technological products. This leads to a reduction in carbon emissions (Apergis et al. 2018). Moreover, the techniques used in production will become more advanced and cleaner with the corresponding advancement in technology. Through technology-intensive innovative production techniques, less energy will be consumed in production, which will reduce $CO_2$ emissions (Grossman and Krueger 1992; Shahbaz et al. 2018; Yin et al. 2015). In other words, the technologies countries employ in their production processes are one of the most important factors in controlling $CO_2$ emissions (Lorente et al. 2018).

The production factors reflect the production capabilities of particular countries (Lall 2000). The best information about the technology level and the production factors of countries is obtained from the products those countries manufacture. If the products in a country are sophisticated enough, it means that the production factors in the country are as well. Along with those factors, the human and physical capital, legal system, institutions, and infrastructure of a country play pivotal roles in sophisticated production (Felipe et al. 2010).

In international trade literature, the technological level of the manufactured products and knowledge-based production structure is expressed by economic complexity. It gives important information about the economic structure and the technological level of a country (Can and Gozgor 2017). According to Hidalgo (2009), the complexity is the reflection of the capabilities and qualifications of countries in terms of products and manufacturing processes.[2] The high value of economic complexity is an indication of how sophisticated the countries' products are (Sweet and Maggio 2015). The degree of economic complexity not only shows the countries' abilities but also demonstrates the diversity of the production of goods and services. Moreover, it provides a holistic view of the scale, structure, and technological changes of a country.

According to Hausmann et al. (2007), economic complexity is an important determinant of economic growth. Many other scholars have concluded that economic complexity makes an important contribution to economic growth (e.g., Strojkoski and Kocarev 2017; Zhu and Li 2016). The product composition and technological level of countries are two important parameters affecting the environmental quality (Yin

[1] This income level differs according to different scholars. Galeotti and Lanza (1999a) calculated it at around \$13,000, while Holtz-Eakin and Selden (1995) and Sengupta (1996) found that the turning points were about \$35,428 and \$8740, respectively.

[2] See Can and Dogan (2017) for more theoretical background on economic complexity.

et al. 2015). Thus, it is expected that economic complexity also has a significant effect on environmental performance. According to Rothman (1998), industries that are harmful to the environment are mostly located in low-income countries. Many citizens of these countries are not aware of the environmental degradation caused by the production process, and they have less sensitivity to the environment. On the other side, high-technology industries that are less harmful to the environment are located in high-income countries (Rothman 1998). According to Kaufmann et al. (1998), the most important factor in reducing environmental degradation is the composition of the products of the country. When products are less sophisticated, it will be harmful to the country's environment.

In this context, it is expected that economic complexity leads to lower $CO_2$ emissions in the high-income country group and higher $CO_2$ emissions in lower middle income and higher middle income country groups. The reason for this can be explained as follows. In the first stage of the development, developing countries tend to specialize in less sophisticated products that are mostly pollution-intensive. For example, the lower and higher middle-income countries that make agricultural products tend towards the textile sector in the early stages of industrialization. The textile sector is more complex and more pollution-intensive than agriculture. In this stage, the products manufactured become more sophisticated, and as a result, significant economic growth is achieved. At the same time, environmental degradation is also expected to increase. However, after a certain level of income, economic structural changes occur. These changes allow the country to shift from energy-intensive industries to technology-intensive industries. The transition from the energy-intensive industries (e.g., textile industry) to the technology-intensive industries (e.g., aircraft industries) may reduce environmental degradation.

There are a limited number of studies that have examined the impact of the economic complexity on the environment. The first study to investigate the effect of economic complexity on the environment belongs was Can and Gozgor's (2017). Using the dynamic ordinary least square (DOLS) method, the study showed that the EKC hypothesis is valid in France and that economic complexity reduces $CO_2$ emissions in this country. Using the fully modified ordinary least square (FMOLS) and DOLS methods, Neagu and Teodoru (2019) tested the effects of economic complexity on the environment in the context of EU countries. Their results revealed that economic complexity increases $CO_2$ emissions in the EU. However, according to Can and Gozgor (2017), the environmental impact of economic complexity is expected to vary according to the income groups of countries. In this context, it is assumed that economic complexity increases $CO_2$ emissions in the group of lower and higher middle income countries, while it reduces $CO_2$ emissions in the group of high-income countries. However, the related studies tested the effect of economic complexity on environmental degradation only in a high-income country (France) and a group of high-income countries (EU members). Thus, there is not a study that analyzes the effect of economic complexity on environmental degradation in countries with different levels of income (lower middle, upper middle, and high-income countries), which is the main objective of this study.

## Data, empirical model, and econometric methodology

$CO_2$ emissions are employed as an indicator of environmental degradation to test the effect of economic complexity and other explanatory variables on the environment. $CO_2$ emissions are measured in metric tons per capita for the 55 countries included in the study over the period 1971–2014. The countries are sorted into three different income levels: high-income, higher middle income, and lower middle income during the period of 1971–2014. The per capita real GDP (per capita constant 2010) and the square of GDP per capita represent the linear and nonlinear effects of income on $CO_2$ emissions, respectively. Energy consumption per capita (kg of oil equivalent per capita) has been included in dynamic experimental models. Urbanization is measured by using the urban population as the share of the total population and trade openness, which is obtained by dividing the sum of exports and imports (volume of trade) by GDP. The data are obtained from the World Development Indicators (WDI) of the World Bank database. The data for the Economic Complexity Index (ECI) are obtained from the Atlas Media database. A higher ECI value means a higher economic complexity. Following recent studies by Zhu et al. (2016) and Apergis et al. (2018), the models below have been taken into consideration.

We model $CO_2$ emissions as a function of the explanatory variables as follows:

$$CO_{2,\mathrm{it}} = f\left(\mathrm{GDP}_{i,t}^{\beta_1}, \mathrm{GDP}_{i,t}^{2,\beta_2}, \mathrm{TE}_{i,t}^{\beta_3}, \mathrm{OP}_{i,t}^{\beta_4}, \mathrm{UR}_{i,t}^{\beta_5}, \mathrm{EC}_{i,t}^{\beta_6}\right) + \mu_{i,t} \quad (1)$$

where $i$ refers to country, $t$ to time, $CO_2$ to per capita carbon dioxide emissions, GDP to per capita income and its square value ($\mathrm{GDP}^2$), TE to per capita total energy use, OP to per capita trade openness, UR to per capita urbanization, and EC to the economic complexity index. All variables are converted to a natural logarithm. The error term is represented by $\mu$. Based on the EKC hypothesis, it is expected that the coefficients of GDP and square of GDP will be statistically significant, with positive and negative signs, respectively. In accordance with the previous studies, the impact of total energy use is expected to be positive ($\beta_3 > 0$). Regarding the effect of trade on environment, a negative sign of the coefficient of trade openness is expected ($\beta_4 < 0$). Trade openness increases the demand for eco-friendly products with higher quality. The coefficient of urbanization might be positive or negative depending on the stage of development of the countries. Finally, the impact of economic complexity on environment is expected to be negative and positive at different levels of income. At the beginning of development process, as a country's income increases, its economic complexity will increase environmental degradation. Thus, a higher level of carbon emissions will be produced. Then, after a certain level of income, a lower level of carbon dioxide emissions will be produced.

Following Zhang et al. (2016) and Flores et al. (2014), we employ the panel quantile regression methodology to take into account the possibility of heterogeneity and to estimate different points of the conditional regional carbon dioxide distribution for a certain period of time (Canay 2011 and Galvao 2011). One of the advantages of this methodology is that it provides more efficient results compared to OLS estimators, where the error terms are not normally distributed. Moreover, this methodology offers the opportunity to perform a detailed evaluation of the carbon dioxide emissions at different per capita income and economic complexity levels in terms of the EKC hypothesis.

Thus, we specify the $\tau$th quantile ($0 < \tau < 1$) of the conditional distribution of the dependent variable given a set of independent variables $X_{i,\ t}$.

$$Q_\tau\left(\frac{CO_{2,\mathrm{it}}}{X_{i,t}}\right) = \alpha_\tau + \beta_\tau X_{i,t} + \alpha_\tau \mu_{i,t} \quad (2)$$

where $X_{i,\ t}$ represents the vector of five independent variables (GDP, GDP$^2$, TE, OP, UR, EC), all in logs, and $\mu_{i,\ t}$ denotes unobservable factors. The parameters of the equation are estimated by minimizing the absolute value of the residuals (Koenker 2004).

$$\left(Q_\tau(\beta_\tau) = \min_\beta \sum_{i=1}^{n} \left[\left|\ln H_{i,t} - \beta_\tau X_{i,t}\right|\right]\right) \quad (3)$$

OLS regression may overestimate the effect of these factors by neglecting heterogeneous distribution. Therefore, it may be more appropriate to select a quantitative regression to examine the factors affecting carbon emissions. In this article, the quantile approach with fixed effects that has been proposed by Canay (2011) is employed. Quantile estimation allows the effect of variables to change with a non-separable distortion term. Most of the existing class-panel data techniques contain the additional fixed term, but this term changes the interpretation of the parameters of interest relative to the cross-sectional regressions (Canay 2011). This is due to the assumption that the distortion term is divided into different components and the parameters do not change according to the constant effect. The estimates obtained can be interpreted as cross-sectional quantile estimates. Therefore, coefficient values show the impact of the explanatory variable in the $\tau$th quantile of the outcome distribution. Finally, in this method, constant effects are never predicted and coefficient estimates are consistent for small $T$. Network research of a generalized quantile regression can be estimated by numerical optimization of the Markov chain Monte Carlo (used here) or Nelder-Mead method (Baker 2016).

## Empirical results

We began the data analysis by performing a pairwise correlation test to observe whether the variables had multiple collinearity problems. As can be seen in Table 1, there was no additional concern for multiple collinearity issues. Panel unit root tests were also performed, and the results showed that taking into account the variables in the logs resulted in data stagnation, for which the results are available on request. Table 2 also provides summary statistics of the data. The highest average value is that of total energy use, which follows the highest standard deviation, while the highest standard deviation represents the second-largest standard deviation of economic complexity and trade openness.

In Table 3, we present results for four cross-sectional dependency tests to be used if ignoring the cross-sectional dependence in estimates could have serious consequences: the Breusch-Pagan LM test; the Pesaran scale LM test; the bias-corrected scaled LM test developed by Baltagi, Feng and Kao; and also the Pesaran CD test results. The deterioration in panel data models is assumed to be cross-sectional, and the tests in Table 3 show that cross-sectional dependence is not present in our panel regression setting. Ignoring the cross-sectional correlation in the estimation of panel models can lead to serious statistical errors.

Tables 4, 5, and 6 present the Canay (2011) panel quantile regression results for high-income, upper middle-income, and lower middle-income countries, respectively. The results of quantile regression for the panel of high-income countries in

**Table 1** Pairwise correlation results

| | dln$CO_2$ | dlnTE | dlnOP | dlnUR | dlnGDP | dlnEC |
|---|---|---|---|---|---|---|
| dln$CO_2$ | 1 | | | | | |
| dlnTE | 0.5643 | 1 | | | | |
| dlnOP | 0.0106 | 0.0333 | 1 | | | |
| dlnUR | 0.0567 | 0.0789 | 0.0011 | 1 | | |
| dlnGDP | 0.1003 | 0.4356 | 0.0456 | 0.0543 | 1 | |
| dlnEC | 0.0223 | 0.0345 | −0.0674 | 0.0044 | −0.0689 | 1 |

The dependent variable is ln$CO_2$ (log of per capita carbon dioxide emissions). GDP and GDP$^2$ refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

**Table 2** Summary statistics

| Variable | | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| $dlnCO_2$ | Overall | 0.0033 | 0.1232 | − 1.5123 | 1.2138 |
| | Between | | 0.0167 | − 0.0356 | 0.0472 |
| | Within | | 0.1123 | − 2.5340 | 1.1914 |
| dlnTE | Overall | 0.0144 | 0.0683 | − 0.3769 | 0.7292 |
| | Between | | 0.0181 | − 0.0098 | 0.1024 |
| | Within | | 0.0612 | − 0.6342 | 0.5398 |
| dlnOP | Overall | 0.0123 | 0.2165 | − 1.8992 | 8.2813 |
| | Between | | 0.0123 | − 0.0165 | 0.0589 |
| | Within | | 0.2162 | − 1.2884 | 8.2921 |
| dlnUR | Overall | 0.0076 | 0.0104 | − 0.0252 | 0.0611 |
| | Between | | 0.0076 | − 0.0066 | 0.0271 |
| | Within | | 0.0072 | − 0.0234 | 0.0477 |
| dlnGDP | Overall | 0.0166 | 0.0519 | − 1.0497 | 0.4314 |
| | Between | | 0.0156 | − 0.0306 | 0.0757 |
| | Within | | 0.0496 | − 1.0593 | 0.4218 |
| dlnEC | Overall | 0.0003 | 0.2644 | − 2.4918 | 2.3673 |
| | Between | | 0.0259 | − 0.1015 | 0.1327 |
| | Within | | 0.2422 | − 2.7248 | 3.2352 |

The dependent variable is $lnCO_2$ (log of per capita carbon dioxide emissions). GDP and $GDP^2$ refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

Table 4 show that based on the signs of the coefficients of the GDP per capita and the square of GDP per capita, the EKC hypothesis has been supported in high-income countries, as has been recognized in other studies. Specifically, the variable of GDP per capita carries a positive and significant coefficient in most of the quantile levels. This shows the positive effect of economic growth on pollution in the first steps of the development path. In the 11th quantile, GDP per capita has a negative and significant coefficient. This shows that in very high-income countries in this group (the high-income group), GDP has a negative effect on $CO_2$ emissions. In another word, in very high-income countries, economic growth will decrease carbon emissions. This implicitly shows that these countries will shortly demonstrate EKC evidence. The square of GDP per capita in all the quantile levels carries statistically significant coefficients with negative signs. The positive and negative sign of GDP per capita and the square of GDP per capita, respectively, support the EKC hypothesis in high-income countries. This shows that high-income countries have reached a level of economic growth that can mitigate carbon emissions, which means such growth is sustainable. The existence of EKC hypothesis in high-income countries is in line with the finding of many studies such as Aldy (2005), Al Sayed and Sek (2013), Apergis and Ozturk (2015, b), Arouri et al. (2012), Churchill et al. (2019), Cole et al. (1997), Dutt (2009), Galeotti and Lanza (1999b), Galeotti et al. (2006), Haseeb et al. (2018), Heidari et al. (2015), Holtz-Eakin and Selden (1995), Iwata et al. (2011), Jebli et al. (2016), Jobert et al. (2011), Lee et al. (2009), Sapkota and Bastola (2017), York et al. (2003), and Zhang et al. (2017).

When the effect of economic complexity on carbon emissions in this panel of high-income countries is considered, it is apparent that economic complexity has a negative and statistically significant effect on $CO_2$ emissions in all the quantiles. The results show that the value of the economic complexity coefficients increases up to the 8th quantile and decreases after that. The negative effect of economic complexity on $CO_2$ emissions shows that high-income countries are gradually diversifying into the production of environmentally friendly goods and services, and importing the goods and services that increase pollution. This shows that environmental knowledge has been accumulated in these countries' sectors, firms, and industries. This result for high-income countries is similar to Can and Gozgor's (2016) findings for France. The effect of other control variables on $CO_2$ emissions is also useful. For example, when the results of the effect of energy consumption on $CO_2$ emissions are reviewed, it is apparent that energy consumption per capita has a statistically significant negative effect on carbon emissions in the panel of high-income countries. This finding shows the obvious shift in high-income countries from the production and consumption of fossil-fuel energy sources to renewable energy sources. The negative effect of energy on $CO_2$ emissions is similar to the findings of the previous studies such as Al-mulali et al. (2015), Gaspar et al. (2017), and Sinha et al. (2017).

**Table 3** Cross-section dependence test

| Tests | $dlnCO_2$ | dlnEC | dlnGDP | dlnOP | dlnTE | dlnUR |
|---|---|---|---|---|---|---|
| Breusch-Pagan LM | 25.11*** | 321.9*** | 75.561*** | 740.965*** | 326.457*** | NA |
| Pesaran scaled LM | 4.202*** | 2.94*** | 3.542*** | 7.355*** | 16.498*** | NA |
| Bias-corrected scaled LM | 6.371*** | 5.86*** | 28.753*** | 8.466*** | 19.654*** | NA |
| Pesaran CD | 1.603*** | 1.40*** | 23.060*** | 6.78*** | 18.148*** | NA |

***Means significant at 1 % level of significance. NA, not available. The dependent variable is $lnCO_2$ (log of per capita carbon dioxide emissions). GDP and $GDP^2$ refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

**Table 4** Canay (2011) estimator of panel quantile regression: results for high-income countries ($12,476 or more)

| Variables | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| dlnGDP | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000** | 0.000*** | 0.000*** | − 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| $dlnGDP^2$ | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000** | − 0.000* | − 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| dlnTE | − 0.002*** | − 0.002*** | − 0.002*** | − 0.002*** | − 0.002*** | − 0.002*** | − 0.002*** | − 0.001*** | − 0.001*** | − 0.001*** | − 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| dlnOP | − 0.129*** | − 0.122*** | − 0.109*** | − 0.091*** | − 0.072*** | − 0.064*** | − 0.059*** | − 0.055*** | − 0.054*** | − 0.054*** | −0.053*** |
| | (0.013) | (0.006) | (0.007) | (0.007) | (0.006) | (0.003) | (0.003) | (0.003) | (0.002) | (0.003) | (0.001) |
| dlnUR | 0.017* | 0.059*** | 0.028* | − 0.001** | − 0.015** | − 0.046*** | − 0.081*** | − 0.109*** | − 0.126*** | − 0.195*** | − 0.241*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.001) | (0.001) | (0.001) | (0.000) |
| dlnEC | − 0.004*** | − 0.005*** | − 0.005*** | − 0.006*** | − 0.006*** | − 0.006*** | − 0.007*** | − 0.008*** | − 0.007*** | − 0.007*** | − 0.004*** |
| | (0.001) | (0.001) | (0.001) | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) | (0.001) | (0.001) | (0.001) |
| Constant | 36.459 | 36.238 | 38.654 | 41.096 | 41.886 | 45.117 | 48.669 | 51.768 | 54.293 | 62.416 | 67.266 |
| | (2.396) | (1.341) | (1.557) | (1.324) | (1.353) | (1.216) | (1.175) | (1.245) | (1.687) | (2.512) | (1.501) |
| Observations | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 | 1012 |

Each pair of rows reports the coefficient estimate and the associated bootstrap standard error in parenthesis for each quantile ($\tau$). ∗∗∗, ∗∗, and ∗ denote statistical significance at the 1 %, 5 %, and 10 % significance levels, respectively. Robust standard errors are in parentheses. The dependent variable is $lnCO_2$ (log of per capita carbon dioxide emissions). GDP and GDP2 refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

The result for the effect of openness on $CO_2$ emissions, meanwhile, show that trade openness has a statistically significant negative effect on carbon emissions in all the quantile levels. This result indicates that environmental regulations and trade policies have helped high-income countries control pollution. The finding of negative coefficients for openness in the panel of high-income countries is in line with the findings of Al-mulali and Ozturk (2016), Al-mulali et al. (2015), Ibrahim and Law (2015), Sinha et al. (2017), and Zhang et al. (2017). The effect of urbanization on $CO_2$ emissions is heterogeneous in different quantiles. Its coefficients are positive up to the 3rd quantile, and negative in the rest of the quantiles. This is logical, and means that in a higher level of development, urbanization has a negative effect on carbon emissions.

The results of quantile regression for the panel of upper middle income countries in Table 5 show that the effect of GDP and square of GDP on $CO_2$ emissions in different quantile levels are heterogeneous, unlike in the panel of high-income countries. The coefficients of GDP per capita are statistically significant and positive at lower quantile levels and are statistically significant and negative at higher quantiles. On the other side, the coefficients of the square of GDP per capita carry negative and statistically significant signs in the lower quantiles (up to 6th quantile level), and positive and statistically significant signs in the higher quantiles. These mixed results do not support the presence of the EKC hypothesis in the upper middle-income countries. This may be due to the presence of different countries with diverse levels of economic development in this panel. We can conclude that most of the countries in this panel have not reached a level of development that would allow them to mitigate and control carbon emissions. In other words, these countries have not arrived at sustainable economic growth yet. The results for the effect of energy consumption on $CO_2$ emissions in upper middle-income countries are similar to those in the panel of high-income countries. This may be attributed to the efforts that upper-middle-income countries have made in regard to the efficient use of energy consumption, replacing fossil fuels with renewable energy sources, investment in green industries, and green technologies innovation.

Turning to the effect of economic complexity on carbon emissions, it is apparent that economic complexity has a positive and statistically significant effect on carbon emissions in upper middle income countries. The production structure is knowledge- and skill-based, indicating substantial economic complexity. Moreover, the economic complexity measure provides a holistic view of the scale, structure, and technological changes of a country. Regarding the finding related to the effect of economic complexity on $CO_2$ emissions in upper middle income countries, it is possible to say that knowledge- and skill-based production has not come into being yet. The effect of openness on $CO_2$ emissions is negative and statistically significant. This implies that trade regulations and policies regarding the control of $CO_2$ emissions have been successful in these countries. The finding of negative coefficients for openness in the panel of upper middle-income countries is in line with the findings of Al-mulali and Ozturk (2016), Al-mulali et al. (2015), Ibrahim and Law (2015), Sinha et al. (2017), and Zhang et al. (2017).

Looking at the effect of urbanization on $CO_2$ emissions in upper middle-income countries, it is apparent that urbanization has a positive and statistically significant effect on carbon emissions in all the quantile levels. The effect of urbanization on pollution is highly related to the country income level. It is negative in high-income and positive in lower income countries. These results are in line with the findings of Poumanyvong and Kaneko (2010).

The results related to the panel of lower middle income countries in Table 6 show that the effects of GDP and square of GDP on $CO_2$ emissions are heterogeneous. The effect of GDP is negative and statistically significant. However, the effect of GDP square is extremely mixed in different quantiles. The negative effect of GDP on $CO_2$ emissions may be attributed to the fact that at the lower level of development, low-income countries are highly dependent on the agricultural, fuel, and mineral production. Based on a report by UNCTAD (2017),[3] 41 % of low-income countries' exports are agricultural products, while 30 % is fuel and 23 % minerals, ores, and metals. Thus, there is not any sign of the presence of the EKC in the panel of low-income countries. Turning to the effect of economic complexity on $CO_2$ emissions in low-income countries, it is apparent from the results that economic complexity has a positive and statistically significant effect on carbon emissions. This may be due to the lower production and export diversity of these countries. Most of them are countries with a high dependence on a single export commodity.

Looking at the effect of energy consumption on carbon emissions, it is apparent that energy has a statistically significant positive effect on $CO_2$ emissions. The positive effect of energy consumption on pollution is due to the heavy dependency of low-income countries on fossil-fuel energy sources. These results are in line with the findings of Apergis and Payne (2010), Aye and Edoje (2017), Kasman and Duman (2015), Pao and Tsai (2010), Saboori and Sulaiman (2013), and Zhang et al. (2017).

The effect of openness on pollution is positive and its coefficients are statistically significant, except at the last quantile level, at which it carries a negative and statistically significant coefficient. This shows that at a higher level of development, openness may have a negative effect on carbon emissions. This is in line with the findings of Al-mulali and Ozturk (2016), Al-mulali et al. (2015), Ibrahim and Law (2015), Sinha et al. (2017), and Zhang et al. (2017).

[3] http://unctad.org/en/pages/PressRelease.aspx?OriginalVersionID=435

**Table 5** Canay (2011) estimator of panel quantile regression: results for upper middle-income countries ($4036 and $12,475)

| Variables | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| dlnGDP | 0.001*** | 0.001*** | 0.001** | 0.000*** | − 0.001*** | − 0.001** | − 0.002*** | − 0.002*** | − 0.004*** | − 0.004*** | −0.004*** |
| | (0.001) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| $dlnGDP^2$ | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | − 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| dlnTE | − 0.011*** | − 0.009*** | − 0.010*** | − 0.011*** | − 0.010*** | − 0.010*** | − 0.010*** | − 0.007*** | − 0.003** | − 0.003*** | −0.003** |
| | (0.001) | (0.001) | (0.000) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| dlnOP | − 0.221*** | − 0.213*** | − 0.189*** | − 0.181*** | − 0.170*** | − 0.151*** | − 0.152*** | − 0.161*** | − 0.189*** | − 0.194*** | −0.199*** |
| | (0.006) | (0.010) | (0.008) | (0.006) | (0.007) | (0.005) | (0.004) | (0.010) | (0.008) | (0.007) | (0.009) |
| dlnUR | 0.225* | 0.188*** | 0.236*** | 0.278*** | 0.280*** | 0.293*** | 0.288*** | 0.270*** | 0.114*** | 0.121*** | 0.090*** |
| | (0.084) | (0.030) | (0.026) | (0.016) | (0.015) | (0.011) | (0.022) | (0.038) | (0.043) | (0.037) | (0.047) |
| dlnEC | − 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000** | 0.000*** | 0.000*** | 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Constant | 37.162 | 37.756 | 37.430 | 38.417 | 39.808 | 40.146 | 42.986 | 44.875 | 58.110 | 62.113 | 67.421 |
| | (1.665) | (0.993) | (1.141) | (1.006) | (1.078) | (1.275) | (1.822) | (3.275) | (2.756) | (2.262) | (2.755) |
| Observations | 585 | 585 | 585 | 585 | 585 | 585 | 585 | 585 | 585 | 585 | 585 |

Each pair of rows reports the coefficient estimate and the associated bootstrap standard error in parenthesis for each quantile ($\tau$). ∗∗∗, ∗∗, and ∗ denote statistical significance at the 1 %, 5 %, and 10 % significance levels, respectively. Robust standard errors are in parentheses. The dependent variable is lnCO2 (log of per capita carbon dioxide emissions). GDP and GDP2 refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

**Table 6** Canay (2011) estimator of panel quantile regression: results for lower middle-income countries (less than $4035)

| Variables | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| dlnGDP | −0.008*** | −0.007** | −0.007*** | −0.006*** | −0.005*** | −0.004*** | −0.004*** | −0.004*** | −0.004*** | −0.002*** | 0.001*** |
| | (0.005) | (0.003) | (0.001) | (0.000) | (0.000) | (0.001) | (0.001) | (0.001) | (0.001) | (0.002) | (0.004) |
| dlnGDP$^2$ | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| dlnTE | −0.002*** | 0.002*** | 0.006*** | 0.010*** | 0.011*** | 0.011*** | 0.010*** | 0.011*** | 0.009*** | 0.016*** | 0.031*** |
| | (0.006) | (0.004) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.004) | (0.006) |
| dlnOP | 0.056** | 0.016** | 0.020*** | 0.016*** | 0.020*** | 0.025*** | 0.021*** | 0.022*** | 0.016** | −0.002** | 0.006** |
| | (0.028) | (0.019) | (0.005) | (0.004) | (0.003) | (0.004) | (0.003) | (0.004) | (0.006) | (0.023) | (0.043) |
| dlnUR | 0.151** | 0.035** | −0.027* | −0.032*** | −0.053*** | −0.079*** | −0.095*** | −0.107*** | −0.127*** | −0.146*** | −0.282*** |
| | (0.067) | (0.044) | (0.014) | (0.011) | (0.006) | (0.008) | (0.007) | (0.011) | (0.015) | (0.052) | (0.084) |
| dlnEC | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000* | 0.000*** | 0.000* | 0.000*** | −0.000** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Constant | 25.326 | 30.068 | 31.153 | 30.190 | 30.232 | 30.635 | 31.442 | 31.773 | 34.317 | 33.769 | 33.251 |
| | (3.242) | (2.479) | (0.645) | (0.378) | (0.270) | (0.379) | (0.358) | (0.605) | (0.568) | (2.193) | (2.173) |
| Observations | 704 | 704 | 704 | 704 | 704 | 704 | 704 | 704 | 704 | 704 | 704 |

Each pair of rows reports the coefficient estimate and the associated bootstrap standard error in parenthesis for each quantile (τ). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % significance levels, respectively. Robust standard errors are in parentheses. The dependent variable is $lnCO_2$ (log of per capita carbon dioxide emissions). GDP and GDP$^2$ refer to logarithmic per capita income and its square value, respectively. lnTE refers to log per capita total energy use, lnOP to log per capita trade openness, lnUR to log per capita urbanization, and lnEC to the log of the economic complexity

The effect of urbanization is positive in the two first quantiles and changes to negative in the rest. Urbanization carries statistically significant coefficients in all the quantiles. This shows that at a higher level of development, urbanization may have a negative effect on carbon emissions. This finding is similar to the findings of Destek et al. (2016), Fan et al. (2006), Sadorsky (2014), and Sharma (2011).

## Conclusion and policy implications

Global warming is one of the most important environmental problems facing countries today. Therefore, scholars have examined the environmental effects of many different parameters. In this study, we tested the effect of economic complexity, which is an important indicator of sophisticated and knowledge-based production structures on the environment over the period of 1971–2014. The study examined 55 countries divided into three groups: lower middle income, higher middle income, and higher income. The empirical results reveal that the EKC hypothesis is valid in high-income and relative in higher middle-income groups. We also detected that there is a *U*-shaped Kuznets curve in the lower middle-income group. The effect of economic complexity on $CO_2$ emissions is different according to the country groups. Therefore, the study concluded that economic complexity increased $CO_2$ emissions in lower middle and higher middle-income countries, whereas it has decreased $CO_2$ emissions in high-income countries. Actually, these are the first findings for the impact of economic complexity at different levels of income. These results show that the economic structure of the countries has significant effects on the environment. It is known that the industrialization efforts in the early stages of development may cause significant changes in the economic structure. These changes may also bring some problems related to environmental degradation. Various environmental policies are carried out when economic complexity has been increased in lower and higher middle income countries. Otherwise, it can be said that the production structure depending on knowledge and skill will have a negative impact on the environment until a certain income level is reached.

In this study, it was determined that economic complexity has different effects on environmental degradation in the context of development. Economic complexity carries a statistically significant and negative sign in the high-income country group, but a statistically significant positive sign for both lower and higher middle-income countries. It is observed that economic complexity increases $CO_2$ emissions in both lower and higher middle-income country groups, and decreases $CO_2$ emissions in the high-income group. The main reason is the fact that in the first stage of development, countries mainly specialize in heavy pollutant industries in which less complex products are manufactured. In other words, high-income countries have gradually shifted from more carbon-intensive to less carbon-intensive production and exports. From this point of view, it is very important for policymakers to implement various environmental policies that will help to decrease $CO_2$ emissions in low- and middle-income countries. For this reason, it is very important that policymakers encourage environmentally friendly investments. In addition, countries' shifting from petroleum-based energy consumption to renewable energy sources is one of the factors that can reduce $CO_2$ emissions. It is of utmost importance that policymakers develop a variety of policies that will increase the production of renewable energy.

The effects of total energy consumption on $CO_2$ emissions vary according to country groups. The energy consumption coefficient is negative and statistically significant in higher middle-income and high-income country groups. In other words, energy consumption decreases $CO_2$ emissions in these country groups. Increasing the share of renewable energy resources in total energy consumption is the main reason for this case. It is also possible that increasing energy efficiency and new innovative technology have reduced fossil-fuel-based energy consumption. However, energy consumption has a positive effect on $CO_2$ emissions in the lower middle-income country group. As a consequence of negative effects on the environment, policymakers need to introduce policies including tax incentives and guaranteed pricing to increase renewable energy consumption.

Trade openness enables new technology transfer to countries. Due to the new technology transfers, $CO_2$ emissions can be reduced. This result is detected in higher middle and high-income country groups. Trade openness has a negative sign and is statistically significant in these country groups. However, we confirmed that trade openness increases $CO_2$ emissions in the lower middle-income country group. In this regard, it is important for policymakers to motivate the private sector to import green technologies.

Urbanization has a positive sign and is statistically significant in lower and higher middle-income country groups. In other words, urbanization increases $CO_2$ emissions. This empirical finding shows that the rate of urbanization puts pressure on the environment in these country groups. In order to reduce this pressure, policymakers should adjust the rate of migration from rural areas to urban areas.

For future studies, the scholar can investigate the effects of economic complexity on the environment by using different time series and panel techniques for a different country or country groups, taking into consideration structural breaks. In addition, country groups can be tested as developed and developing country groups. These efforts will enable us to observe the effects of economic complexity on environmental degradation.

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