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Endogeneity and Nonlinearity in the Environmental Kuznets Curve: A Control Function Approach

Summary: This study investigates the existence and shape of an environmental Kuznets curve (EKC) across 16 developed countries and 58 developing countries during the period 1995-2010. The basic model of the EKC is a polynomial equation of real GDP per capita. The EKC model estimated for CO_2 emission per capita was extended by using control variables, such as trade, urban population, fossil fuel consumption, and service sector. Based on the nonparametric test of poolability of Badi H. Baltagi, Javier Hidalgo, and Qi Li (1996), the relationship was found to have structural stability. A nonparametric pooled regression model was constructed, which allowed functional form flexibility and considered the endogeneity problem often emphasized in the EKC literature. The estimation results show the nonexistence of an EKC for both groups. The study also indicates the existence of nonlinearity and heterogeneity in the relationships between CO_2 emission and the control variables across both groups.

Keywords: Environmental Kuznets curve, CO_2 emissions, Nonparametric models, Endogeneity, Control function approach.

JEL: C14, C23, Q56.

In this study, the relationship between economic development and environmental quality is examined by using nonparametric techniques that consider the endogeneity problem. The shape of this relationship is important in defining an appropriate joint economic and environmental policy. The debates related to this subject are considered around the validity of the environmental Kuznets curve (EKC) hypothesis are considered. This hypothesis implies that in the early stages of economic development, environmental degradation will increase until a certain level of income is reached, and then environmental improvement will occur (Théophile Azomahou, François Laisney, and Nguyen Van Phu 2006).

One of the problems in applying the EKC in empirical studies is the existence of the endogeneity problem. The simultaneous determination between environment and economic development with some control variables might cause the endogeneity problem. To obtain unbiased and consistent estimation results, an estimation method that considers the problem of endogeneity arising from simultaneity should be used. In a nonparametric case, this problem might be solved by the control function approach. Although nonparametric techniques have been used by some studies investigating the existence of the EKC, the endogeneity issue is almost never addressed in models applying nonparametric techniques.

The present study examines the existence of the EKC for two country groups during the period 1995-2010 by using nonparametric techniques that consider the endogeneity problem. These country groups are classified under the Annex of the Framework Convention on Climate Change as Annex II (16 developed countries) and Non-Annex I (58 developing countries). Because panel data are used, the study also investigates whether the poolability assumption is valid or not.

The paper is organized as follows. Section 1 provides a review of the literature on the EKC, focusing substantially on issues related to econometric specifications. Section 2 presents the nonparametric framework of the EKC model specification. The data description and methodology are discussed in Sections 3 and 4, respectively. Estimation results are presented in Section 5. Section 6 presents the conclusions.

1. Literature Review

This section provides a survey of EKC studies that apply different econometric specifications. The relationship between economic development and environmental quality has become increasingly important in the economic development field since the mid-1990s. Economic research on the EKC began with Nemat Shafik and Sushenjit Bandyopadhyay (1992) and Gene M. Grossman and Alan B. Krueger (1991, 1995). The latter served as the background study for the report of the World Bank (1992), through which the concept then came to be widely known. Although these studies used data collected through observation, they provided the existence of the EKC becomes clear through analysis (Katsuhisa Uchiyama 2016). Comprehensive survey studies in this field include those of David I. Stern (1998, 2004), Theodore Panayotou (2000), Susmita Dasgupta et al. (2002), Soumyananda Dinda (2004), Stern (2004), and Romualdas Ginevičius, Giedrė Lapinskienė, and Kęstutis Peleckis (2017), among others.

Recently, development issues, such as alternative sources of energy (biofuels, solar, and wind) and global warming, have re-emphasized the importance of environmental quality in the pursuit of economic development. Thus, questions on the validity of the EKC have continued to emerge.

The literature on the subject is abundant and continues to grow, as do the controversial findings. Van Phu and Azomahou (2007) stated that this controversy is partly due to the wrong functional form specifications used in empirical studies. Particularly in the case of CO_2 emissions, the results of studies exploring the existence of the EKC are the best examples of this controversy. Some studies obtained findings that support the existence of the EKC for CO_2. These include Douglas Holtz-Eakin and Thomas M. Selden (1995), Michael Tucker (1995), Timmons J. Roberts and Peter E. Grimes (1997), Eric Neumayer (2002), Matthew A. Cole (2003), Amy K. Richmond and Robert K. Kaufmann (2006), Maryam Asghari (2012), Muhammad Shahbaz, Aviral K. Tiwari, and Muhammad Nasir (2013), Ceyhun Elgin and Oğuz Öztunalı (2014), Sahbi Farhani et al. (2014), Nicholas Apergis and Ilhan Ozturk (2015), Lapinskienė, Peleckis, and Marijus Radavičius (2015), Hassan Heidari, Salih T. Katircioglu, and Lesyan Saeidpour (2015), Adnan Kasman and Yavuz S. Duman (2015), Adel B.

Youssef, Shawkat Hammoudeh, and Anis Omri (2016), Imad A. Moosa (2017), and Najid Ahmad et al. (2017).

In contrast, other studies showed no evidence of an inverted U-shaped EKC; that is, their findings indicated the nonexistence of an EKC. Examples of these studies include Shafik and Bandyopadhyay (1992), Cole, Anthony J. Rayner, and John M. Bates (1997), Sander M. de Bruyn, Jeroen C. J. M. van den Bergh, and Johannes B. Opschoor (1998), Debabrata Talukdar and Craig M. Meisner (2001), Nico Heenrink, Abay Mulatu, and Erwin Bulte (2001), Elisabetta Magnani (2001), Mark T. Heil and Thomas M. Selden (2001), Mohamed E. H. Arouri et al. (2012), Kun Ho Kim (2013), Khalid Alkhathlan and Muhammad Javid (2013), Setareh Katircioğlu and Salih Katircioğlu (2017). Talukdar and Meisner (2001) stated that the nonexistence of an EKC is supported on grounds that externality has persisted due to the global nature of this pollutant, thereby causing a lack of meaningful policies to abate CO_2 emissions.

It must be noted that all of these have imposed relatively restrictive functional forms, such as quadratic or cubic polynomials. More flexible parametric frameworks (heterogeneous coefficients, spline functions, and data sampling) have been proposed by Richard Schmalensee, Thomas M. Stoker, and Ruth A. Judson (1998), Elbert Dijkgraaf and Herman R. J. Vollebergh (2005), Inmaculada Martinez-Zarzoso and Antonello Maruotti (2013), and Heidari, Katircioglu, and Saeidpour (2015). These studies underlined the crucial role of nonlinearities and heterogeneity across the units of data. Recent studies have introduced semiparametric and nonparametric models to investigate the EKC. The functional form restriction in parametric models is relaxed in semiparametric and nonparametric models, which have been used, for example, by Fatma Taskin and Osman Zaim (2000), Giovanni Baiocchi and Salvatore Di Falco (2001), Azomahou and Van Phu (2001), Luisito Bertinelli and Eric Strobl (2005), Azomahou, Laisney, and Van Phu (2006), Carlos O. Criado (2008), Hui-Ming Zhu, Wan-Hai You, and Zhao-Fa Zeng (2012), George H. Halkos and Nickolaos G. Tzeremes (2013), Rabia Ece Omay (2013), Linna Chen and Shiyi Chen (2015), Bin Xu and Boqiang Lin (2016), Ekpeno L. Effiong and Alex O. Iriabije (2017), and Shahbaz et al. (2017). The details of studies that use nonparametric or semiparametric techniques, flexible parametric techniques, and parametric techniques are given in Appendix Tables A1, A2, and A3, respectively.

To the best of our knowledge, the endogeneity issue arising from reverse causality is almost never addressed for these kinds of models, although nonparametric models have been used by some studies investigating the existence of the EKC.

Jeffrey A. Frankel and Andrew K. Rose (2005), C. Y. Cynthia Lin and Zachary D. Liscow (2012), and Youssef, Hammoudeh, and Omri (2016) are important studies that consider the endogeneity issue arising from the reverse causality in the EKC. However, these works used parametric models to investigate the existence of the EKC. Therefore, the endogeneity issue is mostly not considered for the nonparametric form of the EKC model.

Finally, the studies of Azomahou, Laisney, and Van Phu (2006) and Criado (2008) can be considered as pioneering works that examine the assumption of poolability in nonparametric EKC models that use panel data.

2. Nonparametric EKC Model Specification

A nonparametric specification is constructed to examine the relationship between CO_2 emissions *per capita* and real GDP *per capita*. This specification eliminates the need to identify some particular parametric functional forms, e.g., CO_2 as a linear, quadratic, or cubic function of real GDP *per capita*. Because parametric functional forms are often restrictive and misspecified, the following EKC nonparametric model enhanced by control variables is proposed:

$$Y_{it} = g_{it}(X) + \varepsilon_{it} \text{ with } i = 1, \dots, N; t = 1, \dots, T \tag{1}$$

where Y_{it} represents the *per capita* emissions for CO_2 in country i at time t, and X is the set of explanatory variables, including real GDP *per capita* ($RGDP_{it}$), trade volume in GDP ($TRADE_{it}$), share of urban population in the total population ($URBAN\_POP_{it}$), share of fossil fuels in the total fuel consumption ($FOSSIL\_FUEL_{it}$), and share of the service sector in GDP ($SERVICE_{it}$); ε_{it} is an i.i.d. $(0, \sigma_\varepsilon^2)$ error term.

A major concern with panel data is poolability. The question is whether it is suitable to assume the constancy of parameters or functions over time. Criado (2008) noted that whereas several studies on the existence of EKC have intensively used panel data, few works have addressed the poolability assumption used to model these data. In addition to parametric tests for the poolability of panel data (e.g., the F-test strategy of Hsiao), there is also the nonparametric poolability test of Baltagi, Hidalgo, and Li (1996), which is robust to functional misspecification. The Baltagi, Hidalgo, and Li (1996) J statistic allows the error term to have an arbitrary form of serial correlation or conditional heteroscedasticity in the time dimension or to include individual effects. The J statistic follows an N(0,1) distribution, and the test is one-sided (Baltagi, Hidalgo, and Li 1996; Criado 2008).

In this study, the assumption of temporal homogeneity is tested by applying a nonparametric poolability test, which is robust to functional misspecification. g_{it} ( ) can be assumed to be constant over time; thus, $g_{it}( ) = g_i( )$. Alternatively, g_{it} ( ) we can be assumed to vary over time; thus, $g_{it}( ) \neq g_i( )$. Therefore, the test can be formulated as:

$$H_0: g_{it}(X) = g_i(X);$$
$$H_1: g_{it}(X) \neq g_i(X).$$

H_0 is the temporal homogeneity hypothesis. Accepting H_0 results in the following nonparametric pooled regression:

$$Y_{it} = g(X) + \varepsilon_{it}. \tag{2}$$

The result of the nonparametric poolability test is used to find evidence of the structural stability of the relationship over the period 1995-2010 and to determine which nonparametric model specification should be used.

3. Methodology

The hypothesis that there is no correlation between the error terms and the explanatory variables is a crucial one. If this hypothesis does not hold, then all of the estimators are not valid. In practice, this problem is particularly salient in the presence of reverse causality between the dependent variable and the explanatory variables. In the classic linear model, $Y = X\beta + \varepsilon$, this problem is characterized by $E(\varepsilon|X) \neq 0$. OLS estimation is thus no longer valid, and instrumental variable (IV) estimation is necessary. The principle of IV estimation consists in applying instrumental variables, which are strongly correlated with regressors X but are not correlated with the errors in the model. The endogeneity problem may arise in the nonparametric form of the model, and this issue should also be considered to obtain a consistent estimation of the nonparametric function g(.). To solve this problem, the control function approach, introduced by Whitney K. Newey, James L. Powell, and Francis Vella (1999), can be used (Ibrahim Ahamada and Emmanuel Flachaire 2013). This approach considers a triangular system of the following form:

$$\begin{gathered} Y = g(X, Z_1) + \varepsilon \\ X = m(Z_1, Z_2) + U, E(U|Z_1, Z_2) = 0 \\ E(\varepsilon|Z_1, Z_2, U) = E(\varepsilon|U), \end{gathered} \tag{3}$$

where $X = (X_1, \dots, X_{d_x})'$ is a $d_x \times 1$ vector of endogenous regressors, $Z_1 = (Z_{1_1}, \dots, Z_{1_{d_1}})'$ is a $d_1 \times 1$ vector of "included" exogenous regressors, $Z_2 = (Z_{2_1}, \dots, Z_{2_{d_2}})'$ is a $d_2 \times 1$ vector of "excluded" exogenous regressors, $g(\cdot,\cdot)$ denotes the nonparametric function of interest, $m \equiv (m_1, \dots, m_{d_x})'$ is a $d_x \times 1$ vector of smooth functions of the instruments Z_1 and Z_2, and ε and $U \equiv (U_1, \dots, U_{d_x})'$ are error terms.

Newey, Powell, and Vella (1999) were interested in estimating $g(\cdot,\cdot)$ consistently. They imposed an additivity constraint in each stage to decrease the curse of dimensionality problem and proposed a three-step estimation procedure for an additively separable nonparametric structural equation model. In this approach, the first stage involves separate (additive) regressions of each endogenous regressor on each of the exogenous regressors to obtain consistent estimates of the residuals. These residuals are used in the second-stage regression, in which a single (additive) regression of the response variable is carried out on each of the endogenous regressors (not their predictions), the "included" exogenous regressors, and each of the residuals from the first-stage regressions. The final step involves the estimation of additive components or g(.) functions by using the backfitting algorithm (Deniz Ozabaci, Daniel J. Henderson, and Liangjun Su 2014).

In this approach, the matrix of instruments consists of the included and excluded exogenous regressors. The matrix of instruments, define as W, is strongly correlated with nonparametric endogenous variables X but is not correlated with the errors of the nonparametric model, $E(\varepsilon|W) = 0$, such that: $X = W + v$, where v is a vector of i.i.d errors, which are not correlated with the instruments, $E(v|W) = 0$. If the additional hypothesis $E(\varepsilon|X, v) = \rho v$ is defined, $\varepsilon = \rho v + \eta$ can be written. To avoid the curse of dimensionality problem, nonparametric objects have additive forms. Thus, the nonparametric model is rewritten as:

$$Y = g(X) + g(Z_1) + v\rho + \eta. \tag{4}$$

There is now no problem of endogeneity, given that $E(\eta|X, Z_2, v) = 0$. Therefore, it is possible to obtain consistent estimates of the g(.) functions and ρ parameter.

The application of a conditional expectation over X to the above model, which is then subtracted from the nonparametric model, allows obtaining estimators of both the $\underline{\delta}$ and ρ parameters:

$$Y - E(Y|X) = [g(Z_1) - E(g(Z_1)|X)]\delta + [v - E(v|X)]\rho + \eta. \tag{5}$$

In Equation (5), the unobserved values of v are replaced with the OLS residuals, $\hat{v}$, and the nonparametric estimations $\hat{g}_y$, $\hat{g}_z$, and $\hat{g}_v$ obtained from the regressions of Y, g(Z_1), and $\hat{v}$ on the X variables, are used instead of the conditional expectations. Therefore, the OLS estimation of the model might be shown as follows:

$$Y - \widehat{m}_y = (\widehat{m} - \widehat{m}_z)\delta + (\hat{v} - m_{\hat{v}})\rho + \eta. \tag{6}$$

This model yields consistent estimators of both the δ and ρ parameters and their variances. Furthermore, a simple test of exogeneity can be carried out by using this model, by considering the null hypothesis H_0: $\rho = 0$. In addition, a nonparametric estimation of the model:

$$Y - (\hat{v} - g_{\hat{v}})\rho = g(X) + g(Z_1) + \eta, \tag{7}$$

provides an estimate of the functions g of the nonparametric model. The estimations of the g(.) functions can be obtained by applying the backfitting algorithm (Ahamada and Flachaire 2013).

In this study, trade and real GDP *per capita* variables are possible endogenous variables because of the reverse causality with CO_2 emission *per capita*. For this reason, the endogeneity issue is considered for the EKC models in nonparametric form. Therefore, the X matrix in Equation (4) includes trade and real GDP *per capita* variables as nonparametric endogenous variables. The excluded exogenous variable set for each endogenous variable is determined separately. The excluded exogenous variable set for real GDP *per capita*, which was taken from the literature, includes population, investment, capital, labor, and government expenditure. The second set of excluded exogenous variables for trade includes population, investment, bilateral trade agreements, and common language. The gravity model of trade has largely been used to determine the excluded exogenous variables for the trade variable. Because the set of "excluded" exogenous variables differs for each endogenous variable, the "excluded" exogenous variable matrix can be expressed as Z_2 for real GDP *per capita* and as Z_2* for the trade variable. The instrumental variable matrix consisting of the excluded and included exogenous variables can be denoted as W for real GDP *per capita* and as W* for trade variable.

The matrix of included exogenous variables involves service sector, urban population, and fossil fuel consumption. This matrix is Z_1, as defined in Equation (4).

4. Data

The data set consists of a panel of observations for two different country groups for the period 1995-2010. These country groups belong to Annex II (16 countries) and Non-Annex I (58 countries) in the Annex of the Framework Convention on Climate Change, which classified 171 countries under Annex I (40 countries: Annex II (23), Transition (14), and Others (3)) and Non-Annex I (131 countries). The initial year of the data set was determined based on the period of real GDP *per capita*, which serves as a proxy of economic development. The data on real GDP *per capita* were obtained from Penn World Table (PWT 7.1), a publicly available data set containing information on real GDP *per capita* over the period 1950-2010. However, complete time series data could not be obtained for some countries; among the 171 countries, only 74 countries had complete data for the 1995-2010 period. As the sampling period does not cover the last years, it constitutes one of the most important limitations of the study.

Table 1 Descriptive Statistics and Correlation Matrix, 1995-2010 Periods

Descriptive statistics	Variables					
	CO$_2$	RGDP	TRADE	SERVICE	URBAN_POP	FOSSIL_FUEL
Annex II (16 countries)*						
Mean	8.926	32167.65	72.857	69.143	75.517	74.806
Median	8.883	31671.23	68.055	69.724	76.941	81.268
Maximum	18.200	51798.08	190.109	79.457	90.522	98.526
Minimum	4.553	16318.60	16.679	53.942	51.109	31.984
Std. dev.	2.909	6340.621	32.556	4.773	9.111	18.186
Obs.	256	256	256	256	256	256
Non-Annex I (58 countries)***						
Mean	2.844	5667.329	80.424	51.372	52.231	65.263
Median	1.517	3669.416	71.127	52.110	52.197	69.810
Maximum	36.817	55862.42	439.657	75.441	100	99.929
Minimum	0.017	179.7985	14.772	18.909	9.092	1.794
Std. dev.	4.051	6370.707	52.725	10.689	20.689	27.822
Obs.	928	928	928	928	928	928
Correlations						
Annex II*						
CO2	1.00					
RGDP	0.32	1.00				
TRADE	-0.05	0.31	1.00			
SERVICE	-0.21	-0.21	-0.15	1.00		
URBAN_POP	0.40	0.32	-0.32	0.17	1.00	
FOSSIL_FUEL	0.47	-0.14	0.015	0.19	-0.19	1.00
Non-Annex I***						
CO$_2$	1.00					
RGDP	0.65	1.00				
TRADE	0.25	0.58	1.00			
SERVICE	0.13	0.40	0.09	1.00		
URBAN_POP	0.14	0.51	0.17	0.48	1.00	
FOSSIL_FUEL	0.53	0.44	0.18	0.26	0.42	1.00

Notes: * Australia, Austria, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom. *** Albania, Argentina, Armenia, Azerbaijan, Bangladesh, Benin, Bolivia, Botswana, Brazil, Cambodia, Cameroon, Chile, China, Colombia, Congo, Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Ghana, Honduras, India, Indonesia, Iran, Jordan, Kazakhstan, Kenya, Kyrgyzstan, Macedonia, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Namibia, Pakistan, Panama, Paraguay, Peru, Philippines, Republic of Korea, Singapore, South Africa, Sudan, Tajikistan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen.

Source: Authors' calculations.

The above classification is appropriate because the EKC is used to investigate relationships in economic development. Moreover, Uchiyama (2016) noted that the groups based on the Framework hold the political backgrounds of international negotiations on the global warming issue. Thus, in contrast to several studies, the present work prefers this classification.

Table 1 presents the descriptive statistics and correlation matrix of the variables used in the analysis, with the list of countries shown at the bottom. The variable definitions and sources are provided in Appendix Table A4.

Annex II comprises developed countries, whereas Non-Annex I generally includes developing countries, except for Singapore. Therefore, there is considerable bias in the distribution of both CO_2 emission and real GDP *per capita*, with large deviations between the maximum and median values.

The averages indicate that Annex II countries have a high CO_2 emission, fossil fuel consumption, urban population, and service sector share in GDP but have low real GDP *per capita* compared with the other countries.

5. Empirical Results

The empirical objective is to investigate the existence of the EKC for two country groups (Annex II and Non-Annex I) over the period 1995-2010. That is, the study examines whether or not there is an inverted-U relationship between CO_2 emission and real GDP *per capita* for the two country groups. As previously mentioned, some control variables that may affect CO_2 emission, besides the income variable, are included in the model. These control variables are share of trade volume (i.e., exports + imports) in GDP (TRADE), share of the service sector in GDP (SERVICES), share of fossil fuels in total fuel consumption (FOSSIL_FUEL), and share of urban population in the total population (URBAN_POP).

The literature on EKC often emphasizes that income and trade variables are endogenous. Moreover, the problem of endogeneity is reported to arise from the reverse causality between CO_2 emission and these variables. In the presence of the endogeneity, nonparametric estimation is no longer valid. To mitigate the problem of endogeneity in the nonparametric case, the control function approach is used (Henderson and Christopher F. Parmeter 2015).

In this approach, two separate instrumental variable sets are identified. The variables in the growth literature are used to construct the instrumental variable set for the real GDP *per capita* variable. This set includes population growth, investment, capital, labor, and government expenditure. The gravity model is used to construct an instrumental variable set for the trade variable. The second set of instrumental variables for trade includes population growth, foreign direct investment, bilateral trade agreements, and common language.

Before the nonparametric estimation of EKC models, the nonparametric poolability test statistic of Baltagi, Hidalgo, and Li (1996) is applied to determine whether or not nonparametric functions are constant over time.

The nonparametric test statistics for poolability are 0.485 and 0.747 for Annex II and Non-Annex I, respectively. These are considerably lower than 1.645 (the 95%

value of the standard normal distribution; one-sided test). Hence, the data for the two country groups are poolable.

Table 2 shows the estimation results for Models 1 and 2. Model 1 does not consider the endogeneity and Model 2 takes account of the endogeneity via the control function approach, for two samples over the period 1995-2010. Models 1 and 2 are represented by Equations (8) and (9), respectively:

$$Y = g(X) + \varepsilon \tag{8}$$

with $E(Y|X) = g(X)$ and $E(\varepsilon|X) = 0$,

$$\begin{gathered} Y = g(X, Z_1) + \varepsilon \\ X = m(Z_1, Z_2) + U, E(U|Z_1, Z_2) = 0 \\ E(\varepsilon|Z_1, Z_2, U) = E(\varepsilon|U) \end{gathered} \tag{9}$$

Models 1 and 2 are estimated for each country group mentioned above. The estimation results indicate that all variables in the two models are statistically significant for each country group. Moreover, the significance of v_1 and v_2 indicates the validity of the instrumental variable sets.

Table 2 Estimation Results

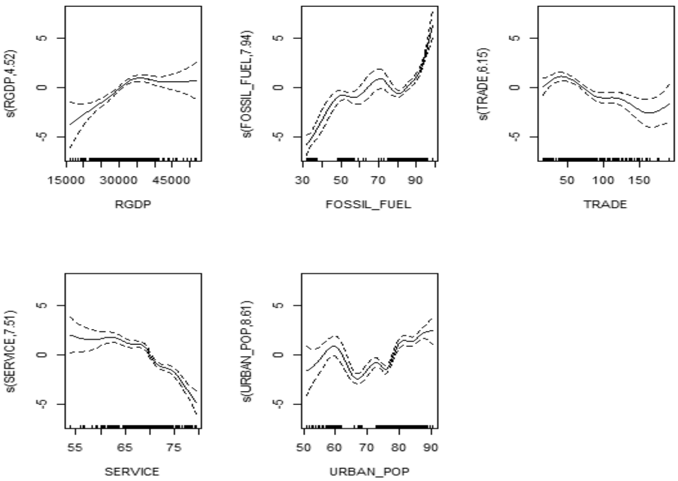
	Model 1		**Model 2**	
	Annex-II	**Non-Annex-I**	**Annex-II**	**Non-Annex-I**
Dependent variable: CO_2				
RGDP	See Figure 1 F-stat: 11.659***	See Figure 1 F-stat: 105.244***	See Figure 2 F-stat: 5.811***	See Figure 2 F-stat: 106.576***
TRADE	See Figure 1 F-stat: 7.879***	See Figure 1 F-stat: 8.698***	See Figure 2 F-stat: 5.477***	See Figure 2 F-stat: 9.078***
SERVICE	See Figure 1 F-stat: 33.463***	See Figure 1 F-stat: 8.206***	See Figure 2 F-stat: 8.371***	See Figure 2 F-stat: 9.103***
URBAN_POP	See Figure 1 F-stat: 27.508***	See Figure 1 F-stat: 70.706***	See Figure 2 F-stat: 13.397***	See Figure 2 F-stat: 69.033***
FOSSIL_FUEL	See Figure 1 F-stat: 52.512***	See Figure 1 F-stat: 108.075***	See Figure 2 F-stat: 39.140***	See Figure 2 F-stat: 77.086***
Instrumental variables:			**t-stat.**	**t-stat.**
v_1	-	-	-0.058** (-2.375)	-0.029*** (-10.510)
v_2	-	-	-0.0002*** (-4.039)	0.0001*** (3.751)
R^2	0.896	0.893	0.86	0.89
Obs.	256	928	256	928

Notes: ***, **, * the coefficient is statistically significant at the 1% level, 5% level, and 10% level respectively. The values in parentheses represent *t* statistics.

Source: Authors' calculations.

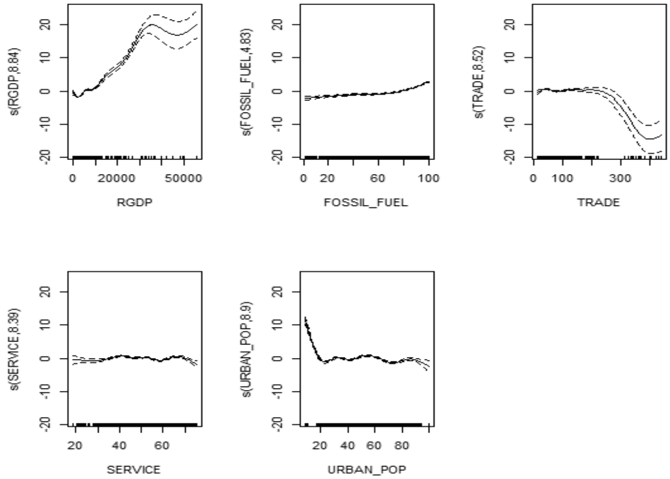
Nonparametric regressions are usually investigated through graphical representations, in which solid curves indicate the estimation of g(.) functions for each nonparametric variable, and dashed curves show the upper and lower 95% confidence intervals. Figures 1 and 2 compare the estimation results of nonparametric pooled regressions that do not consider endogeneity for Annex II and Non-Annex I, respectively.

The graphs in Figures 1 and 2 show that all control variables are related nonlinearly with CO_2 emission *per capita*. Moreover, the nonlinear effects of the control variables on CO_2 emission *per capita* differ significantly from one country group to another.



Source: Authors' calculations.

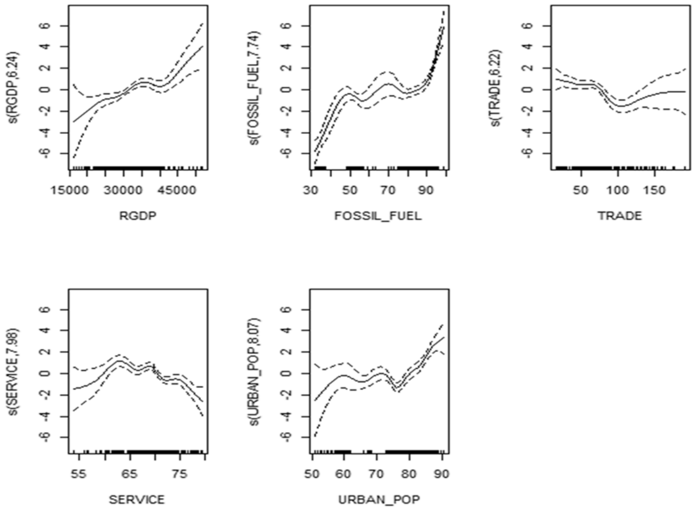
Figure 1 Estimation Results of Nonparametric Pooled Regression without Considering Endogeneity for Annex II. *Solid Curves, Estimated Line; Dashed Curves, Upper and Lower 95% Confidence Intervals*



Source: Authors' calculations.

Figure 2 Estimation Results of Nonparametric Pooled Regression without Considering Endogeneity for Non-Annex I. *Solid Curves, Estimated Line; Dashed Curves, Upper and Lower 95% Confidence Intervals*

Figures 3 and 4 compare the estimation results of nonparametric pooled regressions that consider endogeneity for Annex II and Non-Annex I, respectively. After the endogeneity is mitigated, the nonlinear relationships between variables change considerably for Annex II countries, except for FOSSIL_FUEL. However, the nonlinear relationships between variables do not change for Non-Annex I countries even when the endogeneity is considered. The graphs shown in Figures 3 and 4 are further examined because they are obtained from consistent and unbiased nonparametric estimations considering the endogeneity issue.



Source: Authors' calculations.

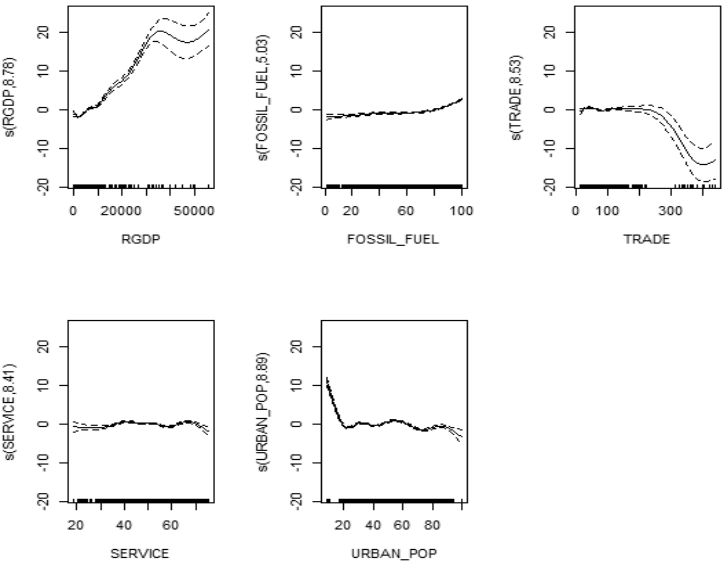
Figure 3 Estimation Results of Nonparametric Pooled Regression Considering Endogeneity for Annex II. *Solid Curves, Estimated Line; Dashed Curves, Upper and Lower 95% Confidence Intervals*

The effects of the control variables for CO_2 are obtained from Figure 3 for Annex II countries. As shown in the figure, there is a monotonically increasing relationship between CO_2 and RGDP, indicating the nonexistence of EKC.

FOSSIL_FUEL increases CO_2, and the rate of increase is fairly high particularly after the level of 80 % is reached.

A decreasing relationship is found between CO_2 and TRADE. After a certain level is reached, an increase in TRADE slightly increases CO_2. Between CO_2 and SERVICE, there is initially an increasing relationship, and then CO_2 decreases after the SERVICE variable reaches 65%.

Urbanization significantly increases CO_2 emission *per capita* after the URBAN_POP variable reaches 75%.



Source: Authors' calculations.

Figure 4 Estimation Results of Nonparametric Pooled Regression Considering Endogeneity for Non-Annex I. *Solid Curves, Estimated Line; Dashed Curves, Upper and Lower 95% Confidence Intervals*

The effects of the control variables for CO_2 are obtained from Figure 4 for Non-Annex I countries. As shown in the figure, there is an N-shaped relationship between CO_2 and RGDP, indicating the nonexistence of the EKC.

FOSSIL_FUEL slightly increases CO_2. However, there is a decreasing relationship between CO_2 and TRADE, which occurs after the TRADE variable reaches 250 %.

The relationship between CO_2 and SERVICE has an almost steady course. Urbanization decreases CO_2 emission *per capita*, but the rate of decrease slows after the URBAN_POP variable reaches 20%.

6. Conclusion

This study investigates the existence and shape of the environmental Kuznets curve by using panel data sets for 16 developed (Annex II) and 58 developing (Non-Annex I) countries over the period 1995-2010. The EKC model is enhanced by considering some control variables that can affect the environmental quality. The model is estimated by applying nonparametric techniques that provide functional form flexibility. However, the simultaneous determination between environmental quality and some control variables results in the endogeneity problem, which produces biased and inconsistent estimations. To avoid this problem, a nonparametric technique that considers the endogeneity problem is used. Moreover, the stability of the relationship in the EKC model over time during the study period is investigated by using the poolability test developed by Baltagi, Hidalgo, and Li (1996). The findings indicate that the model specifications, which assume the stability of the relationship over time during the study period, are valid. This study therefore presents the estimation results of nonparametric pooled regressions that consider the endogeneity problem.

The effect of each variable in the EKC model on CO_2 emission provides remarkable results. The estimation results show the nonexistence of the EKC for both country groups. Moreover, the findings indicate that an increase in real GDP *per capita* increases the CO_2 emission *per capita* in developing countries more than that in developed countries. According to Azomahou, Laisney, and Van Phu (2006), it cannot be ignored that not only developing countries but also developed countries face environmental pollution. This implies that economic development is not a sufficient condition to decrease CO_2 emission. Thus, all countries, especially developed ones because of their valuable resources, should exert efforts to decrease CO_2 emissions.

The relationship between CO_2 emission and fossil fuel consumption differs between the country groups, which may have different fossil fuel consumption structures. In developing countries, the CO_2 emission *per capita* decreases with increasing trade after a high level of trade is achieved. In developed countries, an increase in trade also decreases CO_2 emission even at low levels of trade. This finding is supported by the hypothesis of Grossman and Krueger (1995), who stated that developed countries, which tend to have relatively cleaner urban air and river basins, also have relatively more stringent environmental standards and stricter enforcement of their environmental laws compared with developing countries.

An increase in the share of the service sector in GDP decreases CO_2 emission *per capita* in developed countries, whereas there is a slightly decreasing relationship in developing countries. This finding may be related to the industrial structure of economies. A manufacturing-based economy has more emission-intensive activities than the service sector. Because the industrial structure of developing countries is based on manufacturing, the negative effect of the service sector on CO_2 is not as large as that in developed countries.

The effect of urbanization on CO_2 emission *per capita* is also heterogeneous across the different country groups. There is an increasing relationship between CO_2 emission and the urban population in developed countries. In contrast, there is a decreasing relationship between CO_2 emission and the urban population in developing countries. This finding supports the urban environmental transition theory, which states that the increase in energy consumption among urban residents of developing countries may not be as large as that in developed countries. Developed countries provide more urban amenities than developing countries, and when more urban public services are provided, the consumption of energy resources is likely to be higher.

The present findings generally show the existence of reverse causality and nonlinear relationships between CO_2 emission and the control variables. The sample period clearly presents a limitation of the study given that the application of nonparametric techniques requires more observations to determine the true functional form through the data. Another limitation of the study is the absence of a suitable test for weak instrumental variables in the nonparametric case. Given the importance of the estimation of instrumental variables in applied studies, such tests will no doubt be improved. This is essential for EKC studies because of the reverse causality between CO_2 emission, income, and trade variables, as often emphasized in the literature. Future EKC studies should focus on the aforementioned issues, which are bound to be predominant in estimations.

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Appendix

Table A1 Existing Published Studies that Have Used Nonparametric and Semiparametric Techniques in Environmental Kuznets Curve Estimation

Author(s)	Data period	Countries	Shape of the curve	Types of models used
Taskin and Zaim (2000)	1975-1990	52 (high, middle and low income countries)	N-shaped relationship (EKC confirmed)	Non-parametric: Kernel regression
Azomahou and Van Phu (2001)	1960-1996	100 countries	Monotonic increase for whole sample (EKC not confirmed), Inverted U-shaped relationship for low and high income countries (EKC confirmed) but monotonic increase for middle income countries (EKC not confirmed)	Parametric: Cubic pooled data model Semi-parametric:
Baiocchi and Di Falco (2001)		160 countries	Monotonic increase (EKC not confirmed)	Non-parametric: Local polynomial regression
Bertinelli and Strobl (2005)	1950-1990	108-122 countries	Monotonic increase (EKC not confirmed)	Parametric: Quadratic fixed effects Semi-parametric: Peter M. Robinson (1988)
Azomahou, Laisney, and Van Phu (2006)	1960-1996	100 countries	Monotonic increase for Non-parametric model (EKC not confirmed) Inverted U-shaped relationship for parametric model (EKC confirmed)	Parametric: Within cubic panel estimation Non-parametric: Oliver B. Linton and J. Perch Nielsen (1995); Matthew Wand and Christopher Jones (1995)
Criado (2008)	1990-2002	48 Spanish provinces	Inverted U- shaped relationship (EKC confirmed)	Parametric: Cubic panel fixed effects Semi-parametric: Simon N. Wood (2006) approach
Zhu, You, and Zeng (2012)	1992-2008	20 emerging countries	Monotonic increase (EKC not confirmed)	Semi-parametric: Panel data model with fixed effects
Halkos and Tzeremes (2013)	1996-2010	G-20 countries	U-shaped relationship (EKC not confirmed)	Non-parametric: Pooled regression model
Omay (2013)	1980-2009	Turkey	N-shaped relationship (EKC not confirmed)	Non-parametric: Spline regression approach
Chen and Chen (2015)	1985-2010	31 provinces in China	Inverted-U shaped relationship (EKC confirmed)	Non-parametric: Panel data model with fixed effects
Roberto Martino and Van (2016)	1970-2010	106 countries	Monotonic increase (EKC not confirmed)	Parametric: Quadratic dynamic fixed effects model with instrumental variable approach Semi-parametric: dynamic panel data model with instrumental variable approach
Xu and Lin (2016)	2000-2013	China's manufacturing industry	Inverted-U shaped relationship (EKC confirmed)	Non-parametric: Additive regression models
Effiong and Iriabije (2017)	1990-2010	49 African countries	Non-monotonically increasing (EKC not confirmed)	Semi-parametric: Panel data model with fixed effects
Shahbaz et al. (2017)	1820-2015	G7 countries	Inverted-U shaped relationship (EKC confirmed for Canada, France, Germany, Italy, U.K. and the U.S) (EKC not confirmed for Japan)	Non-parametric: Local linear regression analysis

Source: Authors' calculations.

Table A2 Existing Published Studies that Have Used Flexible Parametric Techniques in Environmental Kuznets Curve Estimation

Author(s)	Data Period	Countries	Shape of the curve	Types of Models Used
Schmalensee, Stoker, and Judson (1998)	1950-1990	141	Inverted U-shaped relationship (EKC confirmed)	Flexible parametric: Piecewise linear function with fixed year and country-specific effects
Dijkgraaf and Vollebergh (2005)	1960-1997	24 OECD countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Polynomial reduced form specifications of country-level emissions as a function of each country's *per capita* income allowing for both country-and time (fixed) effects Flexible parametric: Spline function approach
Martinez-Zarzoso and Maruotti (2013)	1968-2006	28 OECD countries	N-shaped relationship and inverted N-shaped relationship (EKC not confirmed)	Flexible parametric: Robust hidden Markov regression models
Heidari, Katircioglu, and Saeidpour (2015)	1980-2008	Five ASEAN countries (Indonesia, Malaysia, Philippines, Singapore and Thailand)	Inverted U-shaped relationship (EKC confirmed)	Flexible parametric: Panel smooth transition regression model

Source: Authors' calculations.

Table A3 Existing Published Studies that Have Used Parametric Techniques in Environmental Kuznets Curve Estimation

Author(s)	Data Period	Countries	Shape of the curve	Types of Models Used
Holtz-Eakin and Selden (1995)	1951-1986	130 countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic fixed effects
Tucker (1995)	1971-1991	137 countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic cross-sectional regression
Roberts and Grimes (1997)	1962-1991	98-135 countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic cross-sectional regression
Neumayer (2002)	1960-1988	106 countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic fixed effects
Cole (2003)	1975-1995	32 developed and developing countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic random effects
Richmond and Kaufmann (2006)	1973-1997	36 developed (OECD) and developing (non-OECD) countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic, Semi-log, Double-log random coefficient model
Shafik and Bandyopadhyay (1992)	1960-1989	118-153 countries	Monotonic increase (EKC not confirmed)	Parametric: Double-log cross sectional regression model
Cole, Rayner and Bates (1997)	1960-1991	7 regions	Monotonic increase (EKC not confirmed)	Parametric: Quadratic fixed effects model
De Bruyn, van den Bergh, Opschoor (1998)	1961-1993	UK, US, Netherlands, Western Germany	Monotonic increase (EKC not confirmed)	Parametric: Dynamic OLS model
Talukdar and Meisner (2001)	1987-1995	44 developing countries	Monotonic increase (EKC not confirmed)	Parametric: Quadratic random effects model
Heenrink, Mulatu, Bulte (2001)	1985	135 countries	Monotonic increase and non-linear (EKC not confirmed)	Parametric: Quadratic cross-sectional regression model
Magnani (2001)	1970-1990	166 poor countries, 218 middle-income countries, 71 high-income countries	Monotonic decrease (EKC not confirmed)	Parametric: Panel data model with random and fixed effects
Heil and Selden (2001)	1951-1992	135 countries	Monotonic increase (EKC not confirmed)	Parametric: Quadratic fixed effects model
Asghari (2012)	1980-2008	Iran	U-shaped relationship (EKC not confirmed)	Parametric: IV regression model

Shahbaz, Tiwari, and Nasir (2013)	1965-2008	South Africa	Inverted U-shaped relationship (EKC confirmed)	Parametric: ARDL bounds testing approach and error correction method
Elgin and Öztunalı (2014)	1950-2009	Turkey	Inverted U-shaped relationship (EKC confirmed)	Parametric: Cointegration techniques
Farhani et al. (2014)	1990-2010	10 Middle East countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Panel long-run models & Panel Granger causality
Apergis and Ozturk (2015)	1990-2011	14 Asian countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Panel long-run models & Panel cointegration techniques
Lapinskienė, Peleckis, and Radavičius (2015)	1995-2011	20 countries from the EU	Inverted U-shaped relationship (EKC confirmed)	Parametric: Panel data model with fixed effects
Kasman and Duman (2015)	1992-2010	New EU member and candidate countries	Inverted U-shaped relationship (EKC confirmed)	Parametric: Panel long-run models & Panel cointegration techniques & Panel Granger causality
Youssef, Hammoudeh, and Omri (2016)	1990-2012	52 countries (low-income, middle-income, high-income)	Inverted U-shaped relationship (EKC confirmed)	Parametric: Simultaneous-equation models
Moosa (2017)	1960-2014	Australia	Inverted U-shaped relationship (EKC confirmed)	Parametric: Quadratic regression model
Ahmad et al. (2017)	1992Q1-2011Q1	Croatia	Inverted U-shaped relationship (EKC confirmed)	Parametric: ARDL approach & VECM method

Source: Authors' calculations.

Table A4 Variables and Sources

Variable name	Definition	Source
CO_2	CO_2 emissions (metric tons *per capita*)	Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States
RGDP	GDP *per capita* (constant 2005 US$)	PennWorld Table Version 7.1 (PWT 7.1)
TRADE	Trade (% of GDP)	World Bank national accounts data, and OECD National Accounts data files
SERVICE	Services, etc., value added (% of GDP)	World Bank national accounts data, and OECD National Accounts data files
URBAN_POP	Urban population (% of total)	United Nations, World Urbanization Prospects
FOSSIL_FUEL	Fossil fuel energy consumption (% of total)	IEA Statistics © OECD/IEA 2014 (iea.org/stats/index.asp), subject to iea.org/t&c/termsandconditions
CAPITAL	Gross capital formation (% of GDP)	World Bank national accounts data, and OECD National Accounts data files
LABOUR	Labour force participation rate, total (% of total population ages 15+)	International Labour Organization, Key Indicators of the Labour Market database
INVESTMENT	Foreign direct investment, net inflows (% of GDP)	International Monetary Fund, International Financial Statistics and Balance of Payments databases, World Bank, International Debt Statistics, and World Bank and OECD GDP estimates
POPULATION_GROWTH	Population growth (annual %)	Derived from total population. Population source: (1) United Nations Population Division. World Population Prospects; (2) United Nations Statistical Division. Population and Vital Statistics Report (various years); (3) Census reports and other statistical
GOVERNMENT	General government final consumption expenditure (% of GDP)	World Bank national accounts data, and OECD National Accounts data files
AGREEMENT	Bilateral trade agreements	WTO's (2014) regional trade agreement database
LANGUAGE	Common language (official and second languages)	CIA's World Factbook

Source: Authors' own table.