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RESEARCH ARTICLE

Testing the agriculture-induced EKC hypothesis: the case of Pakistan

Korhan K. Gokmenoglu[1] · **Nigar Taspinar**[1]

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Abstract

This study investigates the long-run equilibrium relationship among carbon dioxide (CO_2) emissions, income growth, energy consumption, and agriculture, thus testing the existence of what we call the *agriculture-induced environmental Kuznets' curve* (EKC) hypothesis in the case of Pakistan for the period of 1971–2014. The long-run equilibrium relationship among the variables in the conducted model is confirmed by Maki's (EM 29(5), 2011–2015, 2012) co-integration test under multiple structural breaks. Toda-Yamamoto's (JE 66(1):225–250, 1995) causality test results reveal bidirectional causal relationships among gross domestic product (GDP), energy use, agriculture, and CO_2 emissions. Fully modified ordinary least squares (FMOLS) results suggest that GDP has elastic positive impacts on CO_2 emissions, and energy use and agricultural value added have inelastic positive impacts on CO_2 emissions, whereas squared GDP has an inelastic and negative effect on CO_2 emissions. This finding confirms the existence of the *agriculture-induced EKC hypothesis* in Pakistan and can be a guideline for other agrarian developing countries for the creation of effective policies around environmental degradation.

Keywords Air pollution · Agriculture · Energy consumption · Causality · Pakistan · EKC

JEL classification Q5 · Q1 · Q4 · C01

The history of industrialization can be characterized by the intense use of fossil fuels, mainly petroleum, natural gas, and coal. Fossil fuels have enabled humankind to reach an unprecedented pace of economic growth and level of prosperity, but these developments have come at a cost to the environment. Factors beyond fossil fuel use that accompany economic progress, such as high population growth, advanced transportation, new lifestyles, higher demands and expectations among citizens, and international trade, have further aggravated environmental problems (Alcántara and Padilla 2005; Intergovernmental Panel on Climate Change (IPCC) 2013). The recognition of the high environmental costs of these developments brought the concept of sustainable development onto the agenda, and, since sustainable development was first emphasized in detail in the World Development Report of 1992 (World Bank 1992), the relationship between economic growth and environmental problems has become one of the most investigated and discussed topics among researchers, policymakers, and international organizations (Boluk and Mert 2015).

The economic model known as Kuznets' curve, developed by Simon Kuznets in the 1950s, demonstrates an inverted U-shaped relationship between economic development and income inequality (Kuznets 1955). Kuznets claimed that at the first stage of a nation's economic development, income inequality at first rises then reaches a peak point and, after a threshold point of economic development, then tends to become less severe. Due to the increasing intensity of environmental problems, the well-known Kuznets' curve was modified in the 1990s to describe the relationship between income level and environmental quality.

Following the original idea of Kuznets, Grossman and Krueger (1991, 1993), and Shafik and Bandyopadhyay (1992) independently claimed that there is an approximate inverted U-shaped relationship between income level and environmental quality. This relationship describes how, in the

Responsible editor: Philippe Garrigues

✉ Nigar Taspinar
nigar.taspinar@emu.edu.tr

Korhan K. Gokmenoglu
korhan.gokmenoglu@emu.edu.tr

[1] Banking and Finance Department, Eastern Mediterranean University, via Mersin 10, Famagusta, North Cyprus, Turkey

first stage of a nation's economic development, environmental degradation increases (due to inferior production technologies); while as income levels go up, there is a structural change toward environmentally friendly production processes, at which point environmental degradation begins to diminish. This inverted U-shaped relationship between income and environmental degradation was first named the environmental Kuznets' curve (EKC) by Panayotou (1993). The concept attracted significant interest in the academic world. Following the seminal papers of Shafik and Bandyopadhyay (1992) and Grossman and Krueger (1993), a literature began to emerge and evidence for the validity of EKC hypothesis began to mount (Roberts and Grimes 1997). For the past two decades, a large number of papers have investigated the applicability of the EKC in different countries and in different sample periods, using a variety of empirical approaches.[1] Many researchers have acknowledged its validity.

Agriculture is one of the most important segments of any nation's economy. Although its role as a main driver of economic growth has been acknowledged for several centuries, the information age and globalization have significantly enhanced its importance. Research and development (R&D) in the agricultural sector has a very high rate of return (World Bank 2007), and agriculture is still very important contributor to increases in the total productivity of national economies (Fuglie 2010; Fuglie and Nin-Pratt 2012). Hence, agricultural know-how enables a country to increase its economic growth rate by enhancing its competitiveness. It is well documented that in developing nations, the poverty reduction effect of agricultural growth is greater than that of growth in others sectors (Timmer 2009).

These characteristics of the agricultural sector make it an important tool for developing countries (World Trade Organization (WTO) 2014a). On the other hand, developments over the last two decades in the global food market, including a significant increase in investment interests in agriculture (Deininger et al. 2011), surging R&D attempts, high levels of foreign direct investment (FDI), and higher food standards (Maertens and Swinnen 2014), have brought new challenges and opportunities for developing countries. Increasing volumes of exported agricultural products (The Food and Agriculture Organization (FAO) 2009; WTO 2014b) and greater export shares of developing countries in high value-added product segments motivate developing countries to increase agricultural production. However, more agricultural production leads to greater energy consumption, especially of fossil fuel (United States Census Bureau-USCB 2004–2005; Pimentel 2006; Tabar et al. 2010), and thus to higher levels of carbon emission (Intergovernmental Panel on Climate Change (IPCC) 2006), environmental pollution, deforestation, and poor water quality. The sustainability of agriculture-driven growth has become a vital concern.

For the last two decades, as a result of factors including rising and more volatile energy prices, technological advancements, and changes to environmental policies that govern the relationship between the agriculture and energy sectors, the relationship between the agricultural sector and environmental degradation has transformed. Energy prices rose and were more volatile during 2001–2012. Farmers witnessed an upward trend in the price of energy-related production inputs in this period. On the one hand, this price increase affected the profitability of the agricultural sector and caused changes to the energy usage patterns of the sector (Tokgoz et al. 2008). On the other hand, higher energy prices created incentives for other sectors to find alternative energy sources and the energy sector's use of agricultural products, such as feed stock, as renewable fuel sources increased substantially. Other factors such as domestic energy security, rural economic growth, and environmental awareness accelerated growth in biofuel markets. These processes reinforced linkages between the agricultural and energy sectors, but the traditional one-way relationship between them, in which agriculture uses energy as an input and has been a net energy consumer, has become a two-way, reciprocal relationship. The fact that the agricultural sector has become a supplier of energy inputs, as well as a consumer, makes the agriculture-energy relationship more complicated and important to analyze (Hochman et al. 2010). Technological development has also changed the relationship between agricultural production and energy-environment issues. Both higher fossil fuel prices and the growing sensitivity of the international community to environmental degradation have led to the adoption of alternative technologies and production practices that conserve energy and other inputs. Enhanced energy efficiency not only helps to improve competitiveness through cost reduction, but also reduces greenhouse gas (GHG) emissions and environmental impacts (Alluvione et al. 2011).

Transformations in the agriculture-environment relationship is worth investigating empirically and in the energy use patterns of agricultural systems make agriculture an important candidate for enhancing the conventional EKC model. To the best of the authors' knowledge, there is only one study (DOGAN 2016) in the relevant literature that explores the relationship between changes in the agricultural sector and environmental degradation in terms of the EKC framework. Given the importance of the agricultural sector and its changing relationship to energy-environment issues, augmenting the EKC hypothesis by incorporating the agricultural sector for the case of Pakistan (what we call the agriculture-induced EKC hypothesis) will make an important contribution to the existing empirical literature.

The existing literature discusses both the theory of and the robustness or sensitivity of the estimated EKC models

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[1] Surveys on this topic offer a fairly comprehensive overview (Kijima et al. 2010; Pasten and Figueroa 2012).

(Tutulmaz 2015). Choosing the appropriate econometric approach is vital for the validity of the findings. Previous studies reported mixed results by adopting cross-sectional or panel data analyses to test the EKC hypothesis (Baek 2015). However, Baek and Kim (2011) claim that these mixed results are likely to be results of aggregation bias, which means that an insignificant (significant) income effect with one country could be more than offset by significant (insignificant) income effects with other countries. Furthermore, De Bruyn et al. (1998, p.173) argued "the EKC, as estimated from panel data, does not capture dynamic processes well enough to justify the claim that economic growth is de-linked from environmental pressure in individual countries." To overcome this problem, many researchers prefer to use time series data to investigate individual countries (some recent studies, Aslan et al. 2018; Balaguer and Cantavella 2018; Farhani et al. 2014; Katircioglu and Katircioglu 2017; Lau et al. 2014; Robalino-López et al. 2014). We here use the time series method following the recommendation of Stern et al. (1996) to address the crucial question of the evolution of the income-environment relationship in a specific country and to avoid the issues of cross-sectional dependence (Wagner 2008) and heterogeneity (Dijkgraaf and Vollebergh 2005). We fully address the integration and co-integration properties of the data using more robust and superior econometric techniques than standard econometric procedures. Structural breaks in the series cause errors in the integration and co-integration properties of the series in standard econometric techniques (Perron 1990). In this context, Zivot's and Andrews' (1992) unit root test and Maki's (2012) co-integration test took into account any possible structural break. On the other hand, Toda-Yamamoto's (1995) causality test is employed instead of the standard Granger causality test. One advantage of Toda-Yamamoto's causality test is that it can be applied regardless of the integration and co-integration features of variables in the model (Abu-Bader and Abu-Qarn 2008).

In this study, Pakistan is a case in which the agriculture-induced EKC hypothesis is to be tested. The environmental performance index (EPI), which is a joint project of the Yale Center for Environmental Law & Policy (YCELP) and Columbia University, in collaboration with the World Economic Forum, ranked Pakistan 148th out of 178 countries for environmental performance, indicating serious problems in the environmental policies of the country (2014). Pakistan has an agriculture-based economy, in which the agricultural sector contributed 25.1% of GDP in 2014 and in which 45% of the labor force of the country is engaged with the agricultural sector (World Bank development indicators 2015). Therefore, growth in Pakistan's agriculture sector may accelerate economic growth overall, which could lead to higher energy consumption and hence could be a source of increased CO_2 emissions. In 2050, a threefold increase in energy demand is expected as Pakistan has one of the fastest growing economies in the world (Rafique and Rehman 2017). According to Kyoto protocol agreements on climate change, the Government of Pakistan focuses on the ways of reducing air pollution and ensuring energy efficiency in the country while trying to accelerate economic growth (Mirza and Kanwal 2017). These circumstances make Pakistan an interesting case in which the relationship between CO_2 emissions, economic growth, energy consumption, and agriculture as a test of the agriculture-induced EKC hypothesis is to be investigated, with the ultimate goal of informing effective environmental policy. The results of this study may also help other developing countries to create comprehensive policies to control environmental degradation.

Theoretical framework

The results of empirical analyses that seek to investigate the validity of the EKC hypothesis are dependent on several factors, such as the selection of the dependent variable, independent variables, country and sample period, econometric model, and empirical methods. We assert that choices about the influence granted to these variables in various models are the main sources of conflicting findings on the validity of the EKC hypothesis. Hence, in order to obtain robust and reliable results, it is imperative that one is clear about the decisions made regarding the role and weight of these variables in EKC models.

The EKC describes a relationship between income growth and environmental pollution. Environmental pollution is the dependent variable of the model and can be proxied by several other variables, from changes in biological diversity (Dietz and Adger 2003) to toxic intensity (Seppälä et al. 2001) and to the most commonly used proxy variable (because of its availability), pollutants. Pollutants can be classified in two broad groups: those with local effects and those with global effects. CO_2 is considered a global emission and is one of the most applied emissions in EKC models (Acaravcı and Ozturk 2010; Carson 2010; Cetin 2018; Zilio and Recalde 2011; Osabuohien et al. 2014; Sinha and Shahbaz 2018; Yang and Chen 2014; Yavuz 2014; Al-Mulali et al. 2015a; Zoundi 2017). There are several reasons for this choice. First, carbon emission is a useful variable for policy discussion and recommendation. According to the IPCC (2006), CO_2 represents 76.7% of greenhouse gas (GHG) emissions, which is a vital statistic for decision-makers, for economic planning, and for environmental protection.

Carbon dioxide is directly related to important sustainability problems such as global warming, greenhouse effects, and climate change. Given that a key concern of current international development efforts is the mitigation of global climate change, it is crucial that variables that have an impact on CO_2 emissions be identified (Villanueva 2012). As a global emission, the costs of carbon dioxide extend beyond the time and place in which emissions are generated. This causes so-called free rider problems, in which countries can emit CO_2 without bearing the whole cost of those emissions. The global nature of CO_2 effects often makes it difficult to investigate the relationship between economic growth and pollution in specific contexts, which leads to a lack of consensus in both economics and policy decisions. These challenges make the research interesting. Because of the abovementioned reasons, per capita carbon dioxide emission is used as the dependent variable in our agriculture-induced EKC model.

The EKC represents a reduced form relationship (Grossman and Krueger 1995) that intends to evaluate the "net" or total effect of income growth on environmental quality. Adding nonstructural variables into the EKC model can capture the effect of other variables on the relationship between income growth and environmental degradation depicted by the main reduced model (De Bruyn and Heintz 1999). With the help of nonstructural variables, it might be possible to see a pattern that is masked by the estimation of the reduced form model. Furthermore, the use of nonstructural variables can improve econometric properties and improve the residual quality of the estimations (Tutulmaz 2015). Hence, if it is argued that a variable has a significant influence on environmental quality, then adding this variable to the conventional EKC model will provide better results and enable us to have a better understanding of the relationship under investigation. To this aim, several different variables have been added to the original EKC model in various studies, including labor and capital (Apergis and Payne 2009a, b; Ghali 2004), trade (Jalil and Feridun 2011; Nasir and Rehman 2011; Shahbaz et al. 2014; Zambrano-Monserrate et al. 2018; Zhang 2018), energy consumption (Lean and Smyth 2010; Saboori and Sulaiman 2013; Shahbaz et al. 2015; Ozokcu and Ozdemir 2017), indicators that proxy the use of pollutant energies (Apergis and Ozturk 2015), and the evolution of energy prices (Katircioglu 2017; Richmond and Kaufman 2006). Following recent studies that investigated the relationship between income growth and environmental pollution by incorporating a particular segment of the economy into the EKC model (Katırcıoglu 2014), this study, for the first time, augments the conventional EKC model by including the agricultural sector as an independent variable. This is the main novelty of the paper that we believe will lead to a better understanding of the relationship described by the EKC hypothesis. We further incorporate energy use into the model, as disregarding the role of energy use would generate estimation bias in the results (Balaguer and Cantavella 2016).

The EKC hypothesis has attracted the attention of researchers who have sought to investigate its validity. One reason for this interest is what Tutulmaz (2015) has called the "atomic structure of the model that is suitable to different modeling techniques" (74). Following the seminal paper of Shafik and Bandyopadhyay (1992), researchers have used

Table 1 Zivot's and Andrews' (1992) unit root test

	Statistics (level)			Statistics (first difference)			
	ZA_B	ZA_T	ZA_I	ZA_B	ZA_T	ZA_I	Conclusion
$\ln CO_2$	− 3.274	− 3.291	− 2.859	− 6.428*	− 6.092*	− 6.142*	I(1)
Break year	1994	1995	2008	2004	2007	2010	
Lag length	4	4	4	1	1	1	
lnGDP	− 4.275	− 4.082	− 3.750	− 6.535*	− 5.849*	− 6.397*	I(1)
Break year	1993	1989	1980	2003	1999	1993	
Lag length	2	2	2	0	0	0	
lnGDP2	− 4.517	− 4.000	− 3.743	− 6.299*	− 5.604*	− 6.134*	I(1)
Break year	1997	1989	1980	2003	1999	1993	
Lag length	2	2	2	0	0	0	
lnENG	− 2.914	− 3.002	− 1.307	− 6.428*	− 6.272*	− 6.385*	I(1)
Break year	2004	2007	2007	2004	2005	2007	
Lag length	0	0	0	0	0	0	
lnAGRI	− 4.469	− 3.752	− 3.783	− 8.595*	− 8.496*	− 8.590*	I(1)
Break year	1996	1999	1989	1997	1987	1985	
Lag length	0	0	0	0	0	0	

CO_2 carbon dioxide emissions, *GDP* gross domestic product per capita, *GDP2* the square of gross domestic product per capita, *ENG* energy consumption, *AGRI* agricultural value added. Logarithmic forms of the variables are adopted in the calculations. ZA_B represents the model with a break in the intercept and trend in Eq. (4); ZA_T suggests the model with a break only in the trend in Eq. (5); ZA_I represents the model with a break only in the intercept in Eq. (6)

* The rejection of the null hypothesis at 1% level of significance

several different model specifications to investigate the EKC hypothesis. As introduced above, the EKC hypothesis represents an inverted U-shaped relationship between income growth and environmental quality. The inverted U-shaped relationship between income growth and environmental quality is expressed by the quadratic model of the conventional EKC in the relevant literature (Al-Mulali et al. 2015b; Ang 2007; Apergis and Ozturk 2015; Jalil and Mahmud 2009; Jalil and Feridun 2011; Katircioglu 2014; Katircioglu and Celebi 2018; Pata 2017; Shahbaz et al. 2013; Yavuz 2014) as follows:

$$CO_{2t} = f\left(GDP_t^{\beta_1}, GDP_t^{2\beta_2}, E_t^{\beta_3}\right) \tag{1}$$

Where CO_2 is carbon dioxide emissions (kt), GDP is real income at constant 2010 U.S.$, GDP^2 is squared real income and E is energy consumption.

The agriculture-induced EKC hypothesis can be formulated by adding agriculture as a regressor to the conventional EKC model as follows:

$$\mathrm{CO}_{2t} = f\left(\mathrm{GDP}_t^{\beta_1}, \mathrm{GDP}_t^{2\beta_2}, E_t^{\beta_3}, A_t^{\beta_4}\right) \tag{2}$$

where *A* represents the agriculture value-added constant, per US$ 2010.

The agriculture-induced EKC model in Eq. (2) can be converted to logarithmic form in order to capture growth effects in the long-run as follows:

$$\ln\mathrm{CO}_{2t} = \beta_0 + \beta_1 \ln\mathrm{GDP}_t + \beta_2 \left(\ln\mathrm{GDP}_t\right)^2 + \beta_3 \ln E_t + \beta_4 \ln A_t \tag{3}$$

where $\ln\mathrm{CO}_{2t}$, $\ln\mathrm{GDP}_t$, $\ln\mathrm{GDP}_t^2$, $\ln E_t$, and $\ln A_t$ are logarithmic forms of carbon dioxide emissions, real income, squared real income, energy consumption, and agriculture value-added constant, respectively.

Table 2 The Maki (2012) co-integration test under multiple structural breaks. Empirical model: $\ln\mathrm{CO}_2 = f$ (lnGDP, lnGDP2, lnENG, lnAGRI)

Number of break points	Test statistics [critical values]	Break points
$T_B \leq 1$		
Model 1	− 8.87 [− 5.65]*	2000
Model 2	− 9.58 [− 5.91]*	2012
Model 3	− 8.67 [− 6.52]*	2000
Model 4	− 9.76 [− 6.91]*	1976
$T_B \leq 2$		
Model 1	− 9.21 [− 5.83]*	2000, 2007
Model 2	− 9.99 [− 6.05]*	1983, 2012
Model 3	− 9.16 [− 7.24]*	1975, 2000
Model 4	− 9.76 [− 7.63]*	1976, 1994
$T_B \leq 3$		
Model 1	− 9.46 [− 5.99]*	1992, 2000, 2007
Model 2	− 10.64 [− 6.21]*	1979, 1983, 2012
Model 3	− 9.17 [− 7.80]*	1975, 1989, 2000
Model 4	− 9.76 [− 8.25]*	1976, 1994, 2006
$T_B \leq 4$		
Model 1	− 9.68 [− 6.13]*	1983, 1992, 2000, 2007
Model 2	− 10.93 [− 6.37]*	1977, 1979, 1983, 2012
Model 3	− 11.46 [− 8.29]*	1975, 1989, 2000, 2006
Model 4	− 10.89 [− 8.87]*	1976, 1988, 1994, 2005
$T_B \leq 5$		
Model 1	− 10.21 [− 6.30]*	1978, 1983, 1992, 2000, 2007
Model 2	− 11.62 [− 6.49]*	1977, 1979, 1983, 1989, 2012
Model 3	− 12.37 [− 8.86]*	1975, 1983, 1989, 2000, 2006
Model 4	− 10.89 [− 9.48]*	1976, 1982, 1988, 1996, 2005

Numbers in corner brackets are critical values at 0.05 level from Table 1 of Maki (2012); empirical model: $\ln\mathrm{CO}_2 = f$ (lnGDP, lnGDP2, lnENG, lnAGRI)

*Statistical significance at 0.01 level

Data and methodology

This study adopts annual data covering the period of 1971–2014. Carbon dioxide emissions (kt), gross domestic product per capita constant 2010 US$, energy use (kg of oil equivalent per capita) and agriculture value-added constant 2010 US$ data are collected from World Bank Development Indicators (2017).

Unit root test

The Zivot-Andrews (Zivot and Andrews 1992) unit root test is applied by taking a single structural break in the variables into consideration. The Zivot-Andrews unit root test has three aspects which are applied in the current study. Model I suggests a break in the intercept, model T indicates a break in trend, and model B suggests a break both in intercept and trend. Three models can be represented as follows;

$$\text{Model I}: \quad \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \theta \mathrm{DU}_t + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \epsilon_t \tag{4}$$

$$\text{Model T}: \quad \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma \mathrm{DT}_t + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \epsilon_t \tag{5}$$

$$\text{Model B}: \quad \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \theta \mathrm{DU}_t + \gamma \mathrm{DT}_t + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \epsilon_t \tag{6}$$

where $\mathrm{DU}_t = 1$ and $\mathrm{DT}_t = t - T_b$ if $t > T_b$ and 0 otherwise. T_b and *m* stand for a possible break point and upper limit of the chosen lag length for the dependent variable, respectively.

Table 3 Estimation of long-run coefficients by FMOLS approach

Regressors		Coefficient	Standard error	*P* value
LNGDP		6.234	0.763	0.000
LNGDP2		− 0.396	0.060	0.000
LNENG		0.995	0.107	0.000
LNAGRI		0.506	0.059	0.000
C		− 30.804	3.083	0.000
R-squared	0.998			
S.E. of regr.	0.031			
D-W stat.	1.785			
Long-run variance	0.000			

The Schwarz information criteria are adopted to choose the ideal lag length, and long-run covariance is estimated by the Bartlett-Kernel and the Newey-West fixed bandwidth, which is 4. *S.E. of regr.* the standard error of the regression model, *D-W stat.* the Durbin-Watson test statistics

Co-integration test

Standard co-integration tests do not take into account structural breaks and have errors in estimating long-run relationships among economic variables (Westerlund and Edgerton 2007). There are several co-integration tests that allow only one structural break in the series (Gregory and Hansen 1996; Carron-i-Silvestre and Sanso 2006; Westerlund and Edgerton 2007; Hatemi-j 2008). On the other hand, the number of structural breaks in economic variables is unpredictable especially for emerging economies and considering only one structural break in the economic variables causes misspecifications about estimating long-run relationships between them. Therefore, the Maki (2012) co-integration test considers multiple structural breaks in the series up to five. All of the series should be stationary at their first differences in order to apply the Maki (2012) co-integration test. Maki (2012) proposed four alternative models as follows:

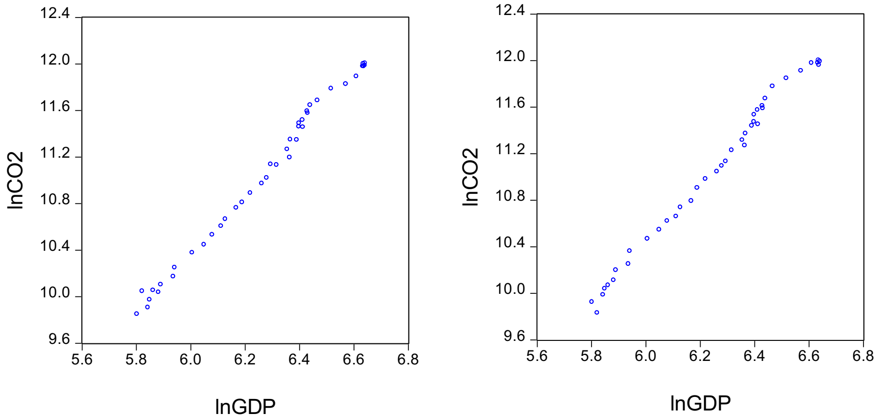
Model 1: with break in intercept and without trend

$$x_t = \mu + \sum_{i=1}^{k}\mu_i D_{i,t} + \beta y_t + u_t \tag{7}$$

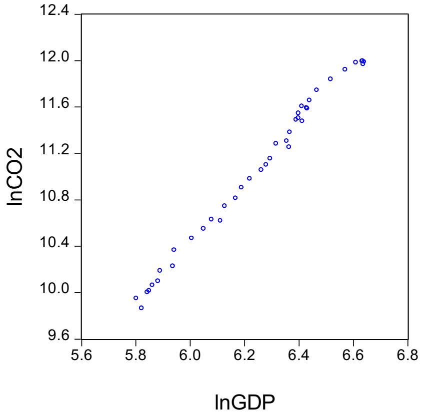
Model 2: with break in intercept and coefficients and without trend

$$x_t = \mu + \sum_{i=1}^{k}\mu_i D_{i,t} + \beta y_t + \sum_{i=1}^{k}\beta_i y_i D_{i,t} + u_t \tag{8}$$

Fig. 1 Actual and estimated EKCs for Pakistan



a) The EKC with Actual CO2 and Actual GDP **b) The EKC with Estimated CO2 and Actual GD with Energy Consumption**



b) The EKC with Estimated CO2 and Actual GDP with Energy Consumption and Agriculture

Table 4 The Toda-Yamamoto (Toda and Yamamoto 1995) causality test

Hypothesis	Chi-square *P* value	Decision
lnGDP does not cause lnCO2	0.067	Reject
lnCO2 does not cause lnGDP	0.000	Reject
lnENG does not cause lnCO2	0.012	Reject
LnCO2 does not cause lnENG	0.006	Reject
lnAGRI does not cause lnCO2	0.082	Reject
lnCO2 does not cause lnAGRI	0.095	Reject
lnGDP does not cause lnAGRI	0.690	Fail to reject
lnAGRI does not cause lnGDP	0.166	Fail to reject
lnAGRI does not cause lnENG	0.304	Fail to reject
lnENG does not cause lnAGRI	0.957	Fail to reject
lnGDP does not cause lnENG	0.036	Reject
lnENG does not cause lnGDP	0.045	Reject

Bootstrapped critical values are calculated with 5000 simulations. The Hacker and Hatemi-J (2012) (HJC) criteria are adopted for the selection of the ideal lag length

Model 3: with break in intercept and coefficients and with trend

$$x_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \gamma y + \beta y_t + \sum_{i=1}^{k} \beta_i y_i D_{i,t} + u_t \tag{9}$$

Model 4: with break in intercept, coefficients, and trend

$$x_t = \mu + \sum_{i=1}^{k} \mu_i D_{i,t} + \gamma t + \sum_{i=1}^{k} \gamma_i t D_{i,t} + \beta y_t + \sum_{i=1}^{k} \beta_i y_i D_{i,t} + u_t \tag{10}$$

where D_i indicates dummy variables as $D_i = 1$ when $t > T_b$ and $D_i = 0$ otherwise and T_b and k stand for a possible break point and upper limit of the chosen lag length, respectively.

Estimation of long-run coefficients

If co-integration test indicates a long-run relationship among variables under investigation, then long-run coefficients have to be estimated to reveal the long run relationship between them. To this aim, fully modified ordinary least squares (FMOLS) approach, which is developed by Phillips and Hansen (1990), will be adopted. The advantage of adopting FMOLS approach is that it corrects endogeneity and serial correlation effects and it eliminates the sample bias error (Narayan and Narayan 2005).

FMOLS model can be estimated as follows:

$$X_t = \beta_0 + \beta_1 Y_t + \mu_t \quad \mathrm{t} = 1, 2, 3, \ldots\ldots\ldots\ldots, n \tag{11}$$

where X_t is an I(1) variable and Y_t is a $(k \times 1)$ vector of I(1) independent variables which are not co-integrated between them.

Causality test

Existence and direction of causal interactions among variables is estimated by the Toda-Yamamoto (1995) causality test. The Toda-Yamamoto (1995) test has more advantageous characteristics. One of the most important advantages of the Toda-Yamamoto causality test is that it is conducted regardless of the integration of the series and co-integration features of models. In order to test the causal interactions among variables, Toda and Yamamoto (1995) suggest the modified Wald stat (MWALD). This method suggests estimating the vector autoregression (VAR) $(k + d_{\max})$. In this model, k is the ideal order and the maximum order of integration is represented as $d_{\max.}$ In this study, bootstrap test is carried out with endogenous lag order which is suggested by Hacker and Hatemi-J (2012) and 10,000 simulations are carried out to calculate bootstrapped critical values. The Hacker and Hatemi-J (2012) information criteria are adopted for the ideal lag selection in the models.

VAR $(k + d_{\max})$ model can be represented as follows:

$$\begin{aligned}
\mathrm{lnCO}_2 = \alpha_0 &+ \textstyle\sum_{i=1}^{k} \alpha_{1i} \mathrm{lnCO}_{2_{t-i}} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} \mathrm{lnCO}_{2_{t-j}} \\
&+ \textstyle\sum_{i=1}^{k} \beta_{1i} \mathrm{lnGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \mathrm{lnGDP}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \delta_{1i} \mathrm{lnENG}_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \mathrm{lnENG}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \gamma_{1i} \mathrm{lnAGRI}_{t-i} + \sum_{j=k+1}^{d_{\max}} \gamma_{2j} \mathrm{lnAGRI}_{t-j} + \varepsilon_{1t}
\end{aligned} \tag{12}$$

$$\begin{aligned}
\mathrm{lnGDP} = \beta_0 &+ \textstyle\sum_{i=1}^{k} \beta_{1i} \mathrm{lnGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \mathrm{lnGDP}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \propto_{1i} \mathrm{lnCO}_{2_{t-i}} + \sum_{j=k+1}^{d_{\max}} \propto_{2j} \mathrm{lnCO}_2 \\
&+ \textstyle\sum_{i=1}^{k} \delta_{1i} \mathrm{lnENG}_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \mathrm{lnENG}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \gamma_{1i} \mathrm{lnAGRI}_{t-i} + \sum_{j=k+1}^{d_{\max}} \gamma_{2j} \mathrm{lnAGRI}_{t-j} + \varepsilon_{2t}
\end{aligned} \tag{13}$$

$$\begin{aligned}
\mathrm{lnENG} = \delta_0 &+ \textstyle\sum_{i=1}^{k} \delta_{1i} \mathrm{lnENG}_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \mathrm{lnENG}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \beta_{1i} \mathrm{lnGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \mathrm{lnGDP}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \propto_{1i} \mathrm{lnCO}_{2_{t-i}} + \sum_{j=k+1}^{d_{\max}} \propto_{2j} \mathrm{lnCO}_{2_{t-j}} \\
&+ \textstyle\sum_{i=1}^{k} \gamma_{1i} \mathrm{lnAGRI}_{t-i} + \sum_{j=k+1}^{d_{\max}} \gamma_{2j} \mathrm{lnAGRI}_{t-j} + \varepsilon_{3t}
\end{aligned} \tag{14}$$

$$\begin{aligned}
\mathrm{lnAGRI} = \gamma_0 &+ \textstyle\sum_{i=1}^{k} \gamma_{1i} \mathrm{lnAGRI}_{t-i} + \sum_{j=k+1}^{d_{\max}} \gamma_{2j} \mathrm{lnAGRI}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \delta_{1i} \mathrm{lnCO}_{2_{t-i}} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} \mathrm{lnCO}_{2_{t-j}} \\
&+ \textstyle\sum_{i=1}^{k} \beta_{1i} \mathrm{lnGDP}_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} \mathrm{lnGDP}_{t-j} \\
&+ \textstyle\sum_{i=1}^{k} \propto_{1i} \mathrm{lnENG}_{t-i} + \sum_{j=k+1}^{d_{\max}} \propto_{2j} \mathrm{lnENG}_{t-j} + \varepsilon_{4t}
\end{aligned} \tag{15}$$

Empirical results

Table 1 reports the integration order of variables by adopting Zivot and Andrews' (1992) unit root test. The unit root test results reveal that the variables used in the study are not stationary at their level forms under one single structural break.

Table 5 Variance decomposition of ln CO_2

Period	S.E.	LNCO2	LNGDP	LNGDP2	LNENG	LNAGRI
1	0.039932	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.055395	84.18412	9.198050	0.025346	1.983601	4.608880
3	0.067847	76.76280	14.36007	0.267265	2.520672	6.089197
4	0.078566	72.52820	17.71094	0.788019	2.504911	6.467936
5	0.088209	69.52029	20.17637	1.576336	2.285125	6.441884
6	0.097125	67.04783	22.10270	2.597897	2.003281	6.248293
7	0.105518	64.83350	23.64739	3.808867	1.727810	5.982426
8	0.113511	62.75834	24.89721	5.162676	1.493994	5.687783
9	0.121182	60.77190	25.90840	6.614295	1.319300	5.386099
10	0.128580	58.85541	26.72215	8.122859	1.210689	5.088892

Therefore, first differences of the variables are taken and the series becomes stationary. That is to say that all variables are integrated of order one under the existence of a single structural break: I(1). Also, the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests are applied as a robustness check for the unit root analysis (see Appendix).

The long-run equilibrium relationship among CO_2 emissions, GDP, the square of GDP, energy use, and agricultural value added was investigated by Maki's (2012) co-integration test under multiple structural breaks. Results of the co-integration test confirm the existence of a long-run equilibrium relationship among variables under multiple structural breaks. Computed test statistics, critical values, and obtained break points under four models of Maki's (2012) co-integration test are reported in Table 2. The null hypothesis, in which there would be no co-integration relationship, is rejected when adopting the four models of Maki (2012) under various multiple structural breaks up to five. Furthermore, the Johansen co-integration and bounds test under autoregressive distributed lag (ARDL) model is applied as a robustness check for confirming the long-run equilibrium relationship among variables (see Appendix).

After revealing the long-run equilibrium relationship among the model's variables, long-run coefficients were obtained by the FMOLS estimation technique. The results of the FMOLS estimation are indicated in Table 3. According to our empirical findings, GDP has elastic positive effect on CO2 emissions, and energy use and agricultural value added have inelastic positive effects on CO_2 emissions, which means income growth and energy use and agricultural development have significant positive effects on air pollution in the case of Pakistan. By contrast, squared GDP has an inelastic and negative impact on CO_2 emissions in the long run. This finding evidences the existence of the agriculture-induced EKC hypothesis in the case of Pakistan.

Figure 1 plots the relationship between (a) actual CO_2 emissions and GDP; (b) estimated CO_2 emissions and actual GDP with energy consumption; and (c) estimated CO_2 emissions with energy consumption and agriculture. Panel a indicates that there is no evidence of an inverted U-shaped relationship between actual CO_2 emissions and GDP. Therefore, the role of energy consumption and agriculture should be taken into account. Panels b and c indicate that the contribution of energy consumption and agriculture to the inverted U-shaped relationship between CO_2 emissions and GDP is not clear. Thus, Fig. 1 suggests that per capita GDP in Pakistan has not reached the level of turning point yet.

The directionality of the long-run relationship among these variables is clarified by Toda-Yamamoto's (1995) causality test. These findings are reported in Table 4. Toda-Yamamoto's causality test results reveal bidirectional causal relationships among GDP, energy use, agriculture, and CO_2 emissions, which indicates that a change in income growth and related changes in energy use and agriculture cause air pollution in Pakistan. Causality test results also reveal that there is a bidirectional relationship between GDP and energy use, which means changes in income growth cause a change in energy use and a change in energy use causes a change in income growth.

Table 5 indicates variance decomposition of CO_2 emissions, where high levels of error forecasts are explained by exogenous shocks to GDP and by increases over time. Error forecast variance of CO_2 emissions by a shock to the GDP is 26.72% in period 10 which means exogenous shocks to the GDP variable explain 26.72% of error forecasts in CO_2 emissions. On the other hand, exogenous shocks to energy consumption explain lower levels of error forecasts in CO_2 emissions rather than exogenous shocks to agriculture. When there is an exogenous shock to agriculture, error forecasts increase in the initial periods but, after some time, error forecasts start to decline. As it can be seen from Table 5, error forecast variance of CO_2 emissions by a shock to the agriculture is at its peak value (6.47%) in the fourth period and it declined to 5.09% in period 10.

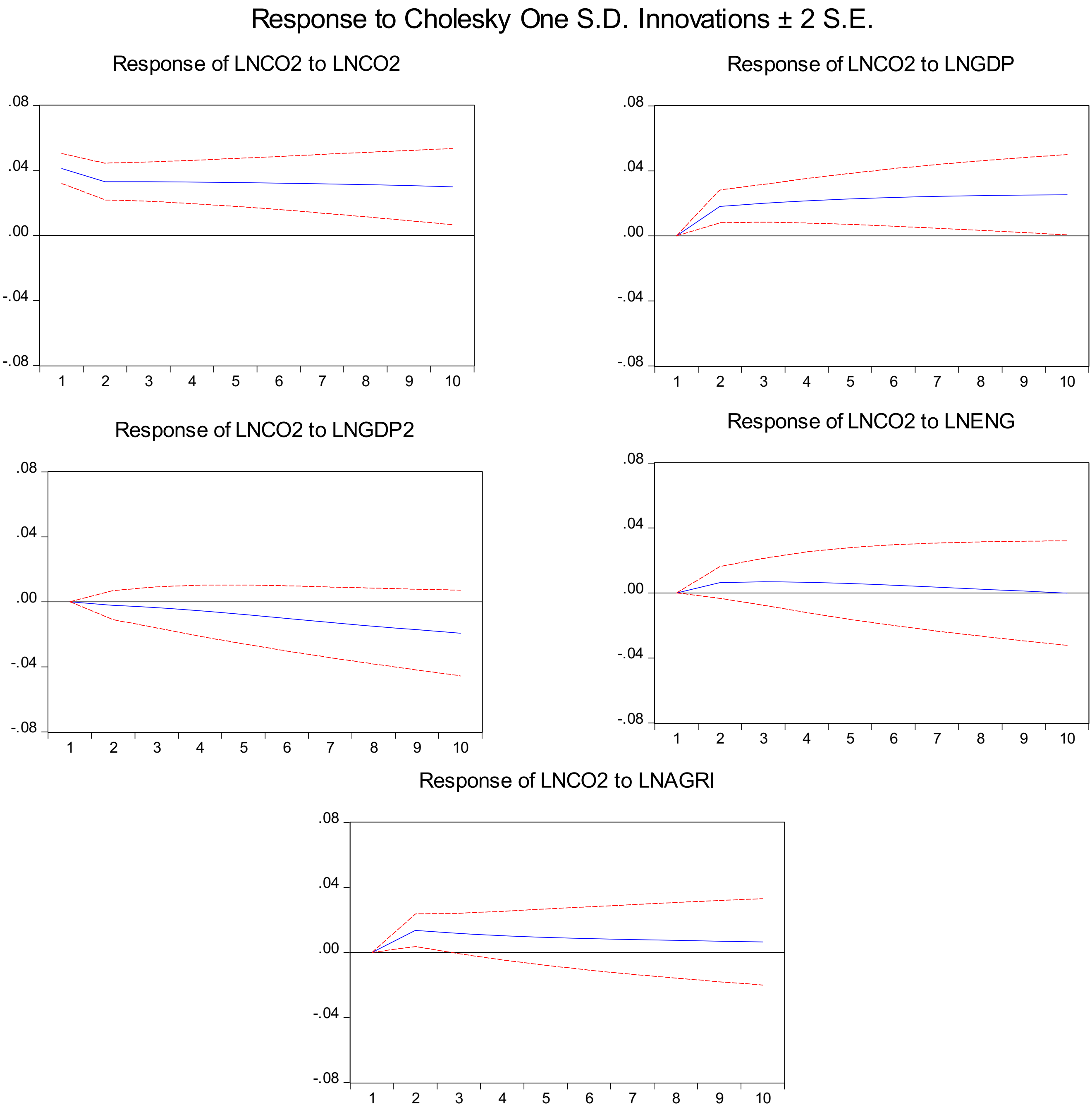


Fig. 2 Impulse responses

Figure 2 plots the impulse responses between CO_2 emissions and its determinants. Impulse responses indicate reactions of the series to exogenous shocks. It is important to use structural information to identify relevant shocks (Lütkepohl 2008). Figure 2 indicates that the response of CO_2 emissions to shocks in the GDP is positive, whereas it is negative when the GDP doubles. Moreover, the response of CO_2 emissions to shocks in energy consumption is very low and decreases over time. Finally, when there is a shock in the agricultural sector, the response of CO_2 emissions is positive in the initial periods but starts to decline over time. These findings support the EKC hypothesis in the case of Pakistan and are consistent with the results of estimated long-run coefficients in Table 3.

Conclusion

This study investigates the validity of the agriculture-induced EKC hypothesis and the long-run equilibrium relationship among CO_2 emissions, income growth, energy consumption, and agriculture in the case of Pakistan for the period of 1971–2014. To the best of our knowledge, this is the only study in the current literature that tests the validity of the EKC hypothesis by adding agriculture to the conventional EKC model for the case of Pakistan. The long-run equilibrium relationship is investigated by adopting Maki's (2012) co-integration test under multiple structural breaks. The results of Maki's (2012) co-integration test confirm the long-run equilibrium relationship under various significant structural breaks up to five among the variables included in the current study.

The validity of the EKC hypothesis can be investigated by comparing estimated long-run coefficients of GDP and squared GDP in the conducted model. If the estimated coefficient of GDP is positive, while the estimated coefficient of squared GDP is negative, the validity of the EKC hypothesis is confirmed for the host country. According to FMOLS regression results, income growth has elastic and positive effects on CO_2 emissions, and energy consumption and agricultural development have inelastic and positive effects on CO_2 emissions which are used as a proxy for air pollution. On the other hand, squared GDP has an inelastic and negative impact on CO_2 emissions in the long run. The results of FMOLS regression suggest the validity of the EKC hypothesis for the case of Pakistan.

Policy makers should be aware not only of the importance of agriculture to the economy of Pakistan but also its effect on environmental degradation. The main cause of air pollution by agriculture sector is burning fossil fuel in the production phase. To reduce the level of pollution, farmers' awareness should be raised to use fossil fuel mode of energy efficiently by investing more in research and development (R&D) activities. Moreover, it is important to invest in clean agriculture while promoting higher income growth and to simultaneously replace polluting forms of energy consumption with renewable energy. By adopting alternative energy resources, coal-fired power stations and emissions from these stations can be reduced. Government also can encourage farmers to use innovative, environmental friendly technologies by adopting a reward mechanism. In other words, farmers who use environmental and innovative techniques in production should be rewarded to decrease the usage of polluting technologies in the sector. In addition, excess usage of fertilizers is one of the main causes of pollution. Government should control the amount of fertilizers used in the production of crops by educating farmers to use fertilizers efficiently. The results of this study can be a guideline for other agrarian developing countries for the creation of effective policies around environmental degradation.

Appendix

Table 6 ADF and PP tests results

Statistics (Level)	$\ln CO_2$	lag	lnGDP	lag	$\ln GDP^2$	lag	lnENG	lag	lnAGRI	lag
τ_T (ADF)	0.529	(1)	−1.596	(1)	−1.769	(1)	0.339	(0)	−2.614	(0)
τ_μ (ADF)	−3.026	(1)	−1.576	(1)	−1.304	(1)	−1.879	(0)	−0.423	(0)
τ (ADF)	3.191	(2)	4.285	(1)	4.083	(1)	4.212	(0)	6.648	(0)
τ_T (PP)	−1.015	(3)	−1.510	(3)	−1.719	(3)	0.339	(0)	−2.614	(0)
τ_μ (PP)	−0.839	(2)	−0.611	(2)	−0.691	(2)	−1.770	(2)	−2.560	(3)
τ (PP)	4.983	(3)	5.670	(3)	5.591	(3)	3.530	(3)	−0.428	(3)
Statistics (first difference)	$\ln CO_2$	lag	lnGDP	lag	$\ln GDP^2$	lag	lnENG	lag	lnAGRI	lag
τ_T (ADF)	−10.148*	(0)	−5.889*	(0)	−5.649*	(0)	−5.697*	(0)	−8.062*	(0)
τ_μ (ADF)	−4.107*	(1)	−5.707*	(0)	−5.565*	(0)	−5.160*	(0)	−8.155*	(0)
τ (ADF)	−4.303*	(1)	−3.003*	(0)	−2.927*	(0)	−3.930*	(0)	−4.273*	(0)
τ_T (PP)	−10.124*	(3)	−5.891*	(1)	−5.649*	(0)	−5.697*	(0)	−8.335*	(3)
τ_μ (PP)	−8.085*	(4)	−5.750*	(2)	−5.574*	(1)	−5.184*	(2)	−8.593*	(5)
τ (PP)	−4.652*	(4)	−2.951*	(3)	−2.858*	(3)	−3.975*	(3)	−4.555 *	(4)

τ_T represents the most general model with a drift and trend; τ_μ is the model with a drift and without trend; τ is the most restricted model without a drift and trend. The numbers in brackets are lag lengths used in ADF test to remove serial correlation in the residuals. When using PP test, the numbers in brackets represent the Newey-West bandwidth (as determined by Bartlett-Kernel). Both in ADF and PP tests, unit root tests were performed from the most general to the least specific model by eliminating trend and intercept across the models. *Rejection of the null hypothesis at the 1% level of significance. Tests for unit roots have been carried out in E-VIEWS 10.0

Table 7 Johansen co-integration test results

Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	5% critical value	1% critical value
None**	0.716162	112.1147	68.52	76.07
At most 1**	0.617625	57.96249	47.21	54.46
At most 2	0.225592	16.62428	29.68	35.65
At most 3	0.122442	5.631063	15.41	20.04
At most 4	0.000343	0.014743	3.76	6.65

Trace test indicates two co-integrating equation(s) at both 5 and 1% levels

*(**) denotes rejection of the hypothesis at the 5% (1%) level

Table 8 Bounds test results

	Null hypothesis: no levels relationship			
	Value	Signif. (%)	I(0)	I(1)
F bounds test				
Test statistic				
		Asymptotic: $n = 1000$		
F statistic	9.391220	10	3.03	4.06
K	4	5	3.47	4.57
		2.5	3.89	5.07
		1	4.4	5.72
Actual sample size	40	Finite sample: $n = 40$		
		10	3.334	4.438
		5	3.958	5.226
		1	5.376	7.092
t bounds test				
Test statistic				
t statistic	− 4.863615	10	− 3.13	− 4.04
		5	− 3.41	− 4.36
		2.5	− 3.65	− 4.62
		1	−3.96	− 4.96

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