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Asymmetric Approach to Investigating the EKC Hypothesis: Evidence from the BRICS Countries

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Abstract

Environmental challenges have emerged as one of the most critical matters affecting the globe today. Human-caused carbon emissions are the primary cause of these environmental challenges, and in order to decrease and mitigate their impacts, officials throughout the world are constantly researching their drivers and determinants. BRICS is considered a significant part of the world economy and energy markets. This study examines the EKC hypothesis for the BRICS while applying a nonlinear ARDL approach that distinguishes it from previous studies. For this purpose, this study decomposes the per-capita income (GPC) series into two components: the positive and the negative series. Empirical findings indicate that in the decomposed model, the coefficients of the positive series of GPC and GPC2 have significant negative and positive signs, respectively, in all countries of the region, which supports the EKC hypothesis. Results imply that BRICS governments need to focus on reducing their very considerable dependence on fossil fuels. The clean energy evolution can lead to the abandonment of fossil fuel assets, including those retained or supported by governments.

Keywords: EKC hypothesis, economic growth, decomposition, BRICS, renewable energy consumption

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1 Introduction

Following the establishment of the World Trade Organization (WTO), reforms in international trade rules reduced tariff and non-tariff barriers and intensified debate about the environmental consequences of trade liberalization. Since the 1970s, the relationship between international commerce and environmental quality has attracted sustained attention; however, trade-related economic expansion may generate environmental pressures that differ across countries and stages of development (De Bruyn et al., 1998; Grossman & Krueger, 1991). As a result, the distribution of pollution and the environmental consequences of economic integration remain important issues in environmental economics (Akram et al., 2022; Wang et al., 2022).

Human societies have entered an era frequently described as the Anthropocene, in which human activities increasingly influence natural systems and environmental conditions (IPCC, 2014; Steffen et al., 2008). Rapid economic expansion may increase energy demand, resource use, and greenhouse gas emissions, thereby contributing to environmental pressures (IPCC, 2007; Rockström et al., 2009). In addition, activities associated with industry, transport, agriculture, and energy production contribute to climate change, although their relative impacts vary across economies (IPCC, 2007, 2014; Tapia Granados & Carpintero, 2013). Consequently, the environmental effects of economic activity have remained an important research concern. The Environmental Kuznets Curve (EKC) hypothesis became prominent during the 1990s as an explanation of a possible nonlinear relationship between economic development and environmental degradation. Kuznets (1955) initially proposed an inverted-U relationship between income inequality and economic development. Subsequently, Grossman and Krueger (1991, 1995) examined the relationship between economic activity and environmental conditions. Under the conventional EKC hypothesis, environmental degradation initially rises with income but may decline after income reaches a particular threshold. However, this relationship is not automatic: technological changes, structural transformation, environmental regulation, and the composition of energy consumption may influence whether environmental improvements accompany higher income (Andreoni & Levinson, 2001; Brock & Taylor, 2010; Stern, 2004).

Subsequent research has examined the relationship between per-capita income and environmental indicators, including carbon dioxide and sulfur dioxide emissions (Grossman & Krueger, 1995; Selden & Song, 1994). However, findings differ across countries, pollutants, periods, and estimation techniques (Andreoni & Levinson, 2001; Brock & Taylor, 2010; Plassmann & Khanna, 2006). For example, evidence of nonlinear income–emissions relationships has been discussed by De Bruyn et al. (1998), Friedl and Getzner (2003), Lindmark (2002), and Martínez-Zarzoso and Bengochea-Morancho (2004). In contrast, other investigations have questioned the stability or general applicability of the EKC hypothesis (Shafik, 1992; Stern, 2004). Cross-country studies also highlight differences in the relationship between income and emissions (Stern & Common, 2001). Similarly, work focused on emerging economies has examined energy consumption, financial development, economic growth, and environmental degradation in BRIC or BRICS contexts (Pao & Tsai, 2010; Tamazian et al., 2009). Halkos (2003) employed panel-data methods to examine the EKC relationship for sulfur emissions. Moreover, studies of income and emissions have reported differing directions of association and causal interactions (Chen & Huang, 2013; Coondoo & Dinda, 2002; Liu, 2005). Some researchers have therefore adopted simultaneous-equation approaches to address possible joint determination of economic activity, energy use, and emissions (Omri, 2013; Omri et al., 2014).

Research on the EKC hypothesis has employed a wide range of estimation strategies and has produced mixed empirical findings. Congregado et al. (2016) investigated the income–emissions relationship in the United States, whereas Shahbaz, Shafiullah, et al. (2017) reconsidered the carbon emissions–growth nexus in G7 economies. Churchill et al. (2018) assessed long-run EKC patterns in OECD countries, and Yilanci and Ozgur (2019) examined time-varying causality for G7 economies. Similarly, Bulut (2019) investigated the United States while allowing for regime shifts and considering renewable energy. In contrast, Baek (2016), Soytas et al. (2007), and Burnett et al. (2013) highlighted the importance of energy composition and model specification when evaluating the environmental consequences of economic activity. Ajmi et al. (2013) examined

time variation in the relationships among emissions, energy consumption, and income, while Dogan and Turkekul (2016) tested the EKC hypothesis for the United States. In addition, Shahbaz, Solarin, et al. (2017) incorporated structural breaks and biomass energy into an EKC analysis. Pablo-Romero and Sánchez-Braza (2017) examined the residential-energy EKC in European Union countries, whereas Sarkodie and Strezov (2018) reported differences across Australia, China, Ghana, and the United States. Other studies have examined differences across US states (Aldy, 2005; Apergis et al., 2017; Atasoy, 2017; Isik et al., 2019; Işık et al., 2019; List & Gallet, 1999). Kahn (1998) further demonstrated how household-level evidence can inform the analysis of nonlinear environmental relationships. Therefore, the literature suggests that EKC findings are sensitive to the estimation method, sampling period, income measurement, and environmental indicator. These differences also motivate closer examination of whether income increases and income decreases are represented adequately in conventional income specifications.

This study investigates the EKC hypothesis for the five BRICS economies—Brazil, Russia, India, China, and South Africa—by decomposing the per-capita income series. Its contribution lies in comparing a conventional, undecomposed income specification with a specification based on the positive partial-sum component of income changes. Conventional EKC models generally represent income through a single series and its squared term; however, movements in income may reflect different episodes of expansion and contraction. Therefore, separating income movements offers an additional way to examine the sensitivity of the estimated income–emissions relationship. The broader literature on decomposition and nonlinear environmental relationships provides a methodological context for this comparison (Ang & Zhang, 2000; Ongan et al., 2021; Tessier & Armstrong, 2015). In addition, earlier EKC studies emphasize that estimated turning points and income effects can vary with specification and country characteristics (Apergis et al., 2017; Stern, 2004). The present study retains its specific focus on positive changes in per-capita GDP when estimating the decomposed EKC relationship. Consequently, its results should be interpreted as evidence from a positive-income decomposition, rather than as a formal statistical comparison of positive and negative income shocks. This distinction clarifies the contribution without altering the study's original objective.

The remainder of the study is organized as follows. Section 2 presents the model and methodology. Section 3 discusses the empirical findings, including unit-root tests, cointegration, and estimated long-run coefficients. Section 4 presents the conclusions and policy implications.

2. Model and Methodology

We examine the EKC proposition for BRICS economies in natural logarithmic form. The model is given as:

$$lnC_t = a_0 + a_1 lnFFEC_t + a_2 lnREC_t + a_3 lnGPC_t + a_4 lnGPC_t^2 + \epsilon_t \quad (1)$$

Table 1: Variables of the Study

Notation	Variables	Source
C_t	"CO2 emission (metric tons per capita)	
$FFEC_t$	Fossil fuel energy consumption (% of total)	
REC_t	Renewable energy consumption (% of total final energy consumption)	World Bank Indicator
GPC_t	GDP per capita (current US$)	World Bank Indicator
GPC_t^2	Square of GDP per capita	World Bank Indicator
GPC_t+	Decomposition of Positive GDP per capita	World Bank Indicator"
GPC_t^2+	Square of Decomposition of Positive GDP per capita"	

Source: Author calculated

Equation 1: C denotes carbon dioxide emissions; FFEC and REC are fossil and per-capita renewable energy consumption; GPC is "real per-capita income"; GPC2 is "real squared per-capita income"; and ϵ_t represents the error term. Here, we examine a potential U-shaped relationship; we prefer to use GPC instead of the traditional and widely used variable, GDP per

capita, as the independent variable to explain demand-side effects on CO2. Next, we have dedecompose the GPC series into positive and negative values as GPC+t and GPC-t, respectively; here, only positive values areo estimate the EKC relationship. Decomposition is based on the following procedure:

$$lnGPC_t^+ = \sum_{j=1}^{t} \Delta lnGPC_j^+ = \sum_{j=i}^{t} \max(\Delta lnGPC_j, 0) \quad (2)$$

$$lnGPC_t^- = \sum_{j=1}^{t} \Delta lnGPC_j^- = \sum_{j=i}^{t} \min(\Delta lnGPC_j, 0) \quad (3)$$

Where GPC_t^+ and GPC_t^- are the of positive and negative values (partial sum process) of GPC. $GPC_t = GPC_0 + lnGPC_t^+ + lnGPC_t^-$ After this decomposition process, we obtain following model based on equation 1 the following model is:

$$lnC_t = a_0 + a_1 lnFFEC_t + a_2 lnREC_t + +a_3 lnGPC_t^2 + a_4 ln(GPC_t^+)^2 + \epsilon_t \quad (4)$$

In the above-mentioned equation, ln $lnGPC_t^2$ and $ln(GPC_t^+)^2$ stand for positive values in "real per-capita income and real squared per-capita income, respectively". The expected sign of a3 is positive, as the effect of real per-capita income on CO2 emissions is direct. Similarly, the expected sign of a4 is negative as after a specific point of rise in real per-capita income, carbon emissions will reduce, over time. Moreover, the expected signs of a_1 and a_2 are positive and negative, respectively. This means that a rise in REC will reduce carbon emissions, while increases in FFEC increase emissions. Significant positive and negative signs of a3 and a4 verify EKC. For both models (un-decomposed and decomposed), we use the "autoregressive distributed lag (ARDL) approach to cointegration" in the following equations 5 and 6, respectively:

$$\Delta lnC_t = b_0 + \sum_{i=1}^{p} b_1 \Delta lnC_{t-i} + \sum_{i=1}^{p} b_2 \Delta lnFFEC_{t-i} + \sum_{i=1}^{p} b_3 \Delta lnREC_{t-i} + \sum_{i=1}^{p} b_4 \Delta lnGPC_{t-i} + \sum_{i=1}^{p} b_5 \Delta lnGPC_{t-i}^2 + b_6 lnC_{t-i} + b_7 lnFFEC_{t-i} + b_8 lnREC_{t-i} + b_9 lnGPC_{t-i} + b_{10} lnGPC_{t-i}^2 + e_t \quad (5)$$

$$\Delta lnC_t = c_0 + \sum_{i=1}^{p} c_1 \Delta lnC_{t-i} + \sum_{i=1}^{p} c_2 \Delta lnFFEC_{t-i} + \sum_{i=1}^{p} c_3 \Delta lnREC_{t-i} + \sum_{i=1}^{p} c_4 \Delta lnGPC_{t-i} + \sum_{i=1}^{p} c_5 \Delta lnGPC_{t-i}^2 + c_6 lnC_{t-i} + c_7 lnFFEC_{t-i} + c_8 lnREC_{t-i} + c_9 lnGPC_{t-i} + c_{10} lnGPC_{t-i}^2 + e_t \quad (6)$$

Equation 5 denotes an undecomposed model; the long-run EKC hypotheses are tested by the magnitude and statistical significance of coefficients b9 and b10, while the short-run theory is tested by the size and significance of b4 and b5. Equation 6 implies that, in the decomposed model, the long-run and short-run EKC theories are analyzed by the magnitudes and significance of coefficientsc_9, c_{10} and c_4, c_5, respectively. The decomposition approach is intended to reduce the possibility that different income movements are concealed within a single aggregate income series. In the EKC setting, it may help identify whether the estimated association between income and environmental degradation depends on how income changes are treated (Ang & Zhang, 2000; Ongan et al., 2021). In addition, the ARDL framework allows short-run adjustments alongside long-run relationships. However, decomposition alone does not establish causal effects, eliminate omitted-variable bias, or demonstrate that positive and negative shocks differ statistically. Therefore, the decomposed model should be interpreted only in terms of the income component used in the analysis. Similarly, evaluate differences between country estimates in relation to their energy structure and the precision of the reported coefficients.

A full nonlinear ARDL analysis would ordinarily retain positive and negative partial sums and test their long-run and short-run equality. Because the present estimates use only the positive

component, the empirical comparison here is between a conventional ARDL specification and an income-positive decomposition rather than a complete two-sided asymmetry test. In addition, the present tables do not report income turning points, dynamic multipliers, or structural-break tests; no numerical values for these analyses are presented.

3. Results

This section presents the empirical analysis and interpretation of the results. First, we examine the stationarity properties of the time-series variables using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit-root tests. The results are reported in Table 2. The tests indicate that the variables display different orders of integration across the five countries. Therefore, the ARDL framework is considered, provided that none of the variables included in the relevant model is integrated of order two, I(2).

Table 2: Unit Root Test

Countries	Variables	ADF		PP	
		I(0)	I(1)	I(0)	I(1)
Brazil	Ct	-0.97	-5.38*	-0.96	-5.38*
	$FFEC_t$	-2.38	-3.74*	-2.22	-3.74*
	REC_t	-2.29	-3.73*	-1.99	-3.73*
	GPC_t	-1.10	-4.39*	-1.20	-4.43*
	GPC_t^2	-1.08	-4.33*	-1.18	-4.36*
	GPC_t+	-3.03**	-5.63*	-3.07**	-6.13*
	GPC_t^2+	-3.44**	-6.24*	-3.46**	-8.24*
China	Ct	-0.74	-3.06**	-0.31	-6.55*
	$FFEC_t$	-0.13	-4.73*	-0.96	-4.77*
	REC_t	2.05	-3.33**	-1.43	-4.60*
	GPC_t	-0.82	-2.94**	-0.34	-2.93**
	GPC_t^2	-0.24	-2.83***	0.32	-2.81***
	GPC_t+	-2.94**	-4.74*	-2.93**	-7.96*
	GPC_t^2+	-2.93**	-5.48*	-2.93**	-8.94*
India	Ct	-0.51	-5.68*	-0.50	-5.67*
	$FFEC_t$	-2.21	-4.86*	-2.25	-4.86*
	REC_t	1.32	-3.32**	0.90	-3.32**
	GPC_t	0.77	-5.71*	0.69	-5.78*
	GPC_t^2	0.98	-5.42*	0.91	-5.49*
	GPC_t+	-4.42*	-6.27*	-4.42*	-14.36*
	GPC_t^2+	-4.74*	-7.85*	-4.74*	-14.61*
Russia	Ct	-2.23	-4.97*	-2.34	-5.11*
	$FFEC_t$	-1.51	-6.84*	-2.14	-19.13*
	REC_t	-2.27	-8.26*	-2.04	-15.53*
	GPC_t	-0.86	-3.40**	-0.64	-3.35**
	GPC_t^2	-0.85	-3.45**	-0.64	-3.40**
	GPC_t+	-2.78***	-6.11*	-2.70***	-10.32*
	GPC_t^2+	-3.006**	-6.51*	-2.94***	-9.26*
South Africa	Ct	-1.99	-5.44*	-2.03	-5.60*
	$FFEC_t$	-1.36	-7.02*	-1.16	-6.84*
	REC_t	-1.46	-4.40*	-1.76	-4.40*
	GPC_t	-1.28	-3.53**	-0.94	-3.46**
	GPC_t^2	-1.28	-3.50**	-0.93	-3.43**
	GPC_t+	-3.61**	-6.04*	-3.59**	-10.38*
	GPC_t^2+	-3.88*	-6.56*	-3.86*	-12.32*

Source: Author calculated. Note: *, ** and *** show 1%, 5% and 10 % level of significance.

The ARDL bounds-testing approach is then employed to examine whether a long-run relationship exists among the variables. The corresponding bounds-test results are presented in Table 3. The model interpretation also follows the broader literature on time-series specifications of the EKC relationship (Ongan et al., 2021; Stern, 2004).

Table 3: ARDL Bound Test

	Un-decomposition				Decomposition				
	F-stat	**Sig**	**I0 Bound**	**I1 Bound**	**F-stat**	**Sig**	**I0 Bound**	**I1 Bound**	**Results**
Brazil	7.76	10%	3.03	4.06	6.60	10%	3.03	4.06	Cointegration
		5%	3.47	4.57		5%	3.47	4.57	
		2.5%	3.89	5.07		2.5%	3.89	5.07	
		1%	4.4	5.72		1%	4.4	5.72	
China	5.13	10%	2.45	3.52	5.55	10%	1.9	3.01	Cointegration
		5%	2.86	4.01		5%	2.26	3.48	
		2.5%	3.25	4.49		2.5%	2.62	3.9	
		1%	3.74	5.06		1%	3.07	4.44	
India	6.88	10%	3.03	4.06	5.29	10%	2.45	3.52	Cointegration
		5%	3.47	4.57		5%	2.86	4.01	
		2.5%	3.89	5.07		2.5%	3.25	4.49	
		1%	4.4	5.72		1%	3.74	5.06	
Russia	5.73	10%	3.03	4.06	4.83	10%	1.9	3.01	Cointegration
		5%	3.47	4.57		5%	2.26	3.48	
		2.5%	3.89	5.07		2.5%	2.62	3.9	
		1%	4.4	5.72		1%	3.07	4.44	
South Africa	5.59	10%	2.45	3.52	4.86	10%	1.9	3.01	Cointegration
		5%	2.86	4.01		5%	2.26	3.48	
		2.5%	3.25	4.49		2.5%	2.62	3.9	
		1%	3.74	5.06		1%	3.07	4.44	

Source: Author calculated

Table 3 reports the ARDL bounds-test results. In the undecomposed models, the reported F-statistics for Brazil, China, India, Russia, and South Africa are 7.76, 5.13, 6.88, 5.73, and 5.59, respectively. The results exceed the corresponding upper-bound critical values at the 5% significance level, supporting a long-run relationship in each country under the reported test specification. However, cointegration by itself does not establish the shape of the EKC relationship; that interpretation also depends on the estimated income and squared-income coefficients.

Similarly, the decomposed-model F-statistics are 6.60 for Brazil, 5.55 for China, 5.29 for India, 4.83 for Russia, and 4.86 for South Africa. Each exceeds the corresponding reported 5% upper-bound critical value in Table 3. Therefore, the reported bounds tests support cointegration in both model specifications, permitting interpretation of the estimated long-run coefficients presented in Table 4. In addition, examine coefficient signs and significance levels separately when assessing EKC consistency.

Table 4: Long Run Coefficients

	Un-decomposition				Decomposition		
	Variables	**Coefficient**	**t-Statistic**	**Prob**	**Coefficient**	**t-Statistic**	**Prob**
Brazil	**FFECt**	1.58	22.19	0.00	1.67	13.40	0.00
	RECt	-0.59	-4.24	0.003	-0.04	-1.09	0.28
	GPCt	0.23	4.90	0.001			
	GPCt2	-0.01	-4.28	0.003			
	GPCt +				0.28	2.267	0.03
	GPCt2+				-0.74	-2.05	0.06

	Un-decomposition				Decomposition			
	Chi-square value	Prob.	Jarque Bera	Prob	Chi-square value	Prob	Jarque Bera	Prob
Normality			0.99	0,60			0.85	0.65
Hetroskedasticity	4.86	0.30			1.52	0.21		
Auto correlation	20.85	0.14			27.93	0.17		

	Variables	Coefficient	t-Statistic	Prob	Coefficient	t-Statistic	Prob
	FFECt	0.03	0.04	0.96	1.30	1.88	0.07
	RECt	-0.35	-2.51	0.03	-0.31	-2.02	0.05
	GPCt	3.26	2.32	0.04			
	GPCt2	-0.18	-1.98	0.07			
China	**GPCt +**				1.13	2.43	0.02
	GPCt2+				-2.91	-1.84	0.07

	Chi-square value	Prob.	Jarque Bera	Prob	Chi-square value	Prob	Jarque Bera	Prob
Normality			1.06	0.58			0.79	0.67
Hetroskedasticity	11.38	0.32			6.42	0.69		
Auto correlation	28.94	0.18			1.55	0.45		

	Variables	Coefficient	t-Statistic	Prob	Coefficient	t-Statistic	Prob
	FFECt	1.11	1.98	0.06	1.09	3.26	0.004
	RECt	-1.23	-1.99	0.05	-0.87	-2.92	0.009
	GPCt	1.08	2.13	0.04			
	GPCt2	-0.08	-2.16	0.04			
India	**GPCt +**				0.56	1.85	0.08
	GPCt2+				-0.88	-3.94	0.00

	Chi-square value	Prob.	Jarque Bera	Prob	Chi-square value	Prob	Jarque Bera	Prob
Normality			3.50	0.17			2.36	0.30
Hetroskedasticity	0.48	0.48			8.92	0.34		
Auto correlation	0.85	0.65			0.75	0.68		

	Variables	Coefficient	t-Statistic	Prob	Coefficient	t-Statistic	Prob
	FFECt	1.02	0.93	0.36	1.06	23.75	0.00
	RECt	-0.33	-2.07	0.05	-1.84	-11.16	0.00
	GPCt	-0.62	-2.22	0.04			
	GPCt2	0.04	2.48	0.02			
Russia	**GPCt +**				0.54	1.97	0.08
	GPCt2+				-0.59	-3.05	0.01

	Chi-square value	Prob.	Jarque Bera	Prob	Chi-square value	Prob	Jarque Bera	Prob
Normality			0.70	0.70			0.92	0.63
Hetroskedasticity	0.11	0.73			0.90	0.34		
Auto correlation	4.11	0.12			14.40	0.15		

	Variables	Coefficient	t-Statistic	Prob	Coefficient	t-Statistic	Prob
	FFECt	1.67	1.51	0.15	0.94	76.67	0.00
South	**RECt**	0.56	1.90	0.07	0.71	37.98	0.00
Africa	**GPCt**	8.48	2.67	0.01			
	GPCt2	-0.50	-2.68	0.01			

	Un-decomposition				Decomposition			
	GPCt +				0.29		3.41	0.009
	GPCt2+				-1.08		-3.38	0.009
	Chi-square value	Prob.	Jarque Bera	Prob	Chi-square value	Prob	Jarque Bera	Prob
Normality			2.62	0.26			2.22	0.32
Hetroskedasticity	0.17	0,73			0.09	0.76		
Auto correlation	3.96	0.13			2.78	0.24		

Source: Author calculated

An inverted-U coefficient pattern should also be distinguished from an economically meaningful EKC turning point. The implied income threshold depends on the exact functional form and coefficient scale and should be evaluated against each country's observed income range. Because the manuscript does not provide these calculations or the underlying data range, we interpret the results in terms of the reported coefficient signs and statistical significance, without asserting that any threshold was crossed.

The undecomposed results in Table 4 indicate that Russia does not exhibit the conventional inverted-U coefficient pattern: its income coefficient is negative, and its squared-income coefficient is positive. In contrast, the remaining four countries report positive income and negative squared-income coefficients, although individual significance levels differ. In the decomposed specification, the positive-income component has a positive coefficient, and its squared term has a negative coefficient in each of the five countries. However, some of these estimates are statistically significant only at the 10% level; therefore, the evidence should not be described as equally strong across all countries. In addition, the renewable-energy coefficients are generally negative for China, India, and Russia, whereas South Africa displays a positive coefficient in the decomposed model and Brazil's decomposed coefficient is not statistically significant at conventional levels. Thus, the estimated effect of renewable-energy consumption should be discussed on a country-specific basis. Fossil-fuel consumption is positively associated with carbon emissions in several country specifications, reinforcing the relevance of changes in energy composition. For energy-importing economies, domestic renewable-energy development may also affect energy security; however, the reported regressions do not directly estimate trade-balance effects (Pao & Tsai, 2010; Tamazian et al., 2009).

4. Conclusion and Policy Implications

The study focuses on the original five BRICS economies because of their substantial roles in economic activity, energy demand, and carbon emissions. In addition, the transition to cleaner energy aligns with these economies' environmental and energy-security priorities. However, their economic structures, energy mixes, and stages of development differ, making country-specific interpretations necessary (Pao & Tsai, 2010; Tamazian et al., 2009).

This study examines the EKC hypothesis for the five BRICS economies using a specification that distinguishes it from the conventional undecomposed model. For each country, the per-capita income series is separated into components associated with increases and decreases; however, only the positive-income component enters the reported decomposed EKC model. This choice reflects the study's original interest in how rising income relates to environmental degradation. The conventional EKC hypothesis proposes that emissions initially increase with income and subsequently decline after a turning point, implying a positive coefficient on income and a negative coefficient on squared income (Grossman & Krueger, 1995; Stern, 2004).

In contrast, the undecomposed income series incorporates both upward and downward movements over time. Consequently, the decomposition may reveal a relationship that is less apparent in a conventional specification. Nevertheless, because the reported decomposed estimates exclude the negative-income component, the analysis does not provide a formal test of whether positive and negative income changes affect emissions differently. The results should

therefore be interpreted within the scope of the positive-component specification. The reported diagnostic tests assess residual normality, heteroscedasticity, and serial correlation. Their results do not indicate statistically significant heteroscedasticity or serial correlation at the conventional levels reported in Table 4. Nevertheless, such diagnostics do not replace tests for parameter stability, structural breaks, or the plausibility of the estimated EKC turning point.

The undecomposed results do not support the conventional inverted-U EKC coefficient pattern for Russia, whereas the other four countries show positive income and negative squared-income coefficients. By contrast, the decomposed model produces positive coefficients for the income component and negative coefficients for its squared term across the five economies. However, not all individual coefficients are significant at the 5% level. Therefore, the findings suggest that the positive-income decomposition changes the observed EKC pattern, particularly for Russia, rather than establishing uniformly strong evidence of an EKC in every country. Similarly, the presence of a turning point within the observed income range has not been demonstrated in the reported results and should not be presumed. The comparison illustrates the importance of model specification when interpreting income–environment relationships (Ongan et al., 2021; Stern, 2004).

The findings suggest that BRICS policymakers should evaluate fossil-fuel dependence alongside the opportunities and constraints associated with renewable-energy development. In addition, investment in energy efficiency and cleaner production technologies may assist emissions-reduction strategies (Akram et al., 2022; Pacala & Socolow, 2004). However, the differences in estimated renewable-energy coefficients indicate that a uniform policy prescription would be inappropriate. Country-specific infrastructure, energy-system composition, and implementation conditions should therefore guide transition policy design. The potential exposure of fossil-fuel assets to a low-carbon transition also warrants consideration, although the present models do not estimate it directly.

The present findings both correspond with and differ from earlier research on the Environmental Kuznets Curve. Similar to studies that examine nonlinear income–environment relationships, the decomposed specification indicates an inverted-U coefficient pattern for the positive-income component (Grossman & Krueger, 1995; Ongan et al., 2021). However, the conventional specification yields a different pattern for Russia, showing how empirical conclusions may depend on how income changes are treated. Previous studies have likewise emphasized variation across country samples, estimation methods, and energy structures (Apergis et al., 2017; Sarkodie & Strezov, 2018; Stern, 2004). In addition, studies of income and energy consumption suggest that the environmental implications of economic development cannot be separated from fossil-fuel use and the composition of energy supply (Pao & Tsai, 2010; Tamazian et al., 2009). The present analysis compares undecomposed income with the positive component of income changes for the original five BRICS economies. Nevertheless, its interpretation is limited by omitting the negative component from the decomposed model and by the absence of reported turning-point calculations and further stability checks. Future research could assess both positive and negative income changes explicitly, examine whether their long-run coefficients differ, test structural breaks, and estimate country-specific turning points. These extensions would build on the study's original research aim while providing a more complete basis for subsequent comparative research and policy assessment.

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References

Akram, R., Umar, M., Xiaoli, G., & Chen, F. (2022). Dynamic linkages between energy efficiency, renewable energy along with economic growth and carbon emission: A case of MINT countries, an asymmetric analysis. *Energy Reports*, 8, 2119–2130.

Ajmi, A. N., Hammoudeh, S., Nguyen, D. K., & Sato, J. R. (2013). On the relationships between CO2 emissions, energy consumption and income: The importance of time variation. *Energy Economics*, *49*, 629–638.

Akram R, Umar M, Xiaoli G, Chen, F (2022) Dynamic linkages between energy efficiency, renewable energy along with economic growth and carbon emission. A case of MINT countries an asymmetric analysis. *Energy Rep*, *8*, 2119–2130.

Aldy, J. E. (2005). An environmental Kuznets curve analysis of US state-level carbon dioxide emissions. *The Journal of Environment & Development*, *14*(1), 48-72.

Andreoni, J., & Levinson, A. (2001). The simple analytics of the environmental Kuznets curve. *Journal of Public Economics*, *80*(2), 269–286.

Ang, B. W., & Zhang, F. Q. (2000). A survey of index decomposition analysis in energy and environmental studies. *Energy*, *25*(12), 1149-1176.

Anjum, N. A., Aref, I. M., Duarte, A. C., Pereira, E., Ahmad, I., & Iqbal, M. (2014). Glutathione and proline can coordinately make plants withstand the joint attack of metal (loid) and salinity stresses. *Frontiers in Plant Science*, *5*, 1-4.

Apergis, N., Christou, C., & Gupta, R. (2017). Are there environmental Kuznets curves for US state-level CO2 emissions?. *Renewable and Sustainable Energy Reviews*, *69*, 551-558.

Arellano, M., & Bond, S. (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies*, *58*(2), 277-297.

Armstrong, J. S., Green, K. C., & Graefe, A. (2015). Golden rule of forecasting: Be conservative. *Journal of Business Research*, *68*(8), 1717-1731.

McGrath, J. E., Jennifer, I., Berdahl, & Arrow, H. (1995). *Traits, expectations, culture, and clout: The dynamics of diversity in work groups. - PsycNET*. American Psychological Association Washington, DC, 17-45.

Baek, J. (2016). Do nuclear and renewable energy improve the environment? Empirical evidence from the United States. *Ecological indicators*, *66*, 352-356.

Brock, W. A., & Taylor, M. S. (2010). The green Solow model. *Journal of Economic Growth*, *15*(2), 127–153.

Bulut, U. (2019). Testing environmental Kuznets curve for the USA under a regime shift: the role of renewable energy. *Environmental Science and Pollution Research*, *26*, 14562-14569.

Burnett, J. W., Bergstrom, J. C., & Wetzstein, M. E. (2013). Carbon dioxide emissions and economic growth in the US. *Journal of Policy Modeling*, *35*(6), 1014-1028.

Chen, J. H., & Huang, Y. F. (2013). The study of the relationship between carbon dioxide (CO2) emission and economic growth. *Journal of International and Global Economic Studies*, *6*(2), 45-61.

Churchill, S. A., Inekwe, J., Ivanovski, K., & Smyth, R. (2018). The environmental Kuznets curve in the OECD: 1870–2014. *Energy Economics*, *75*, 389-399.

Cole, M. W., Ren, F., & Pearton, S. J. (1997). Materials Characterization of WSi Contacts to n+-GaN as a Function of Rapid Thermal Annealing Temperatures. *Journal of the Electrochemical Society*, Retrieved from: https://iopscience.iop.org/article/10.1149/1.1838007/pdf

Congregado, E., Feria-Gallardo, J., Golpe, A. A., & Iglesias, J. (2016). The environmental Kuznets curve and CO 2 emissions in the USA: Is the relationship between GDP and CO 2 emissions time varying? Evidence across economic sectors. *Environmental Science and Pollution Research*, *23*, 18407-18420.

Coondoo, D., & Dinda, S. (2002). Causality between income and emission: A country group-specific econometric analysis. *Ecological Economics*, *40*(3), 351–367.

De Bruyn, S. M., Van Den Bergh, J. C. J. M., & Opschoor, J. B. (1998). Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves. *Ecological Economics*, *25*(2), 161–175.

Deschênes, O., & Greenstone, M. (2007). The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *American Economic Review*, *97*(1), 354–385.

Dogan, E., & Turkekul, B. (2016). CO 2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research*, *23*, 1203-1213.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353–377.

Grossman, G., & Krueger, A. (1991). Environmental Impacts of a North American Free Trade Agreement. National Bureau of Economic Research (NBER Working Paper No. 3914), Cambridge.

Grossman, G. M., & Krueger, A. B. (1995). he modificado este articulo. *Quarterly Journal of Economics*, *110*(2), 353-377.

Halkos, G. E. (2003). Environmental Kuznets Curve for sulfur: evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics*, *8*(4), 581–601.

IPCC. (2014). Foreword, Preface, Dedication and In Memoriam. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, UK: Cambridge University Press

IPCC, I. P. O. C. C. (2007). Climate Change 2007 - The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Retrieved from: https://www.ipcc.ch/report/ar4/wg1/

Isik, C., Ongan, S., & Özdemir, D. (2019). The economic growth/development and environmental degradation: evidence from the US state-level EKC hypothesis. *Environmental Science and Pollution Research*, *26*, 30772-30781.

Kuznets, S. (1955). Economic growth and income inequality. The American Economic Review, 45(1), 1–28.

Kahn, M. E. (1998). A household level environmental Kuznets curve. *Economics Letters*, *59*(2), 269-273.

Kuznets, S. (1955).. *The American Economic Review*, *45*(1), 1-28.

Lee, S. Y., Choi, K. K., Jeong, H. H., Choi, H. S., Oh, T. H., Song, J. O., & Seong, T. Y. (2009). Wafer-level fabrication of GAN-based vertical light-emitting diodes using a multi-functional bonding material system. *Semiconductor Science and Technology*, *24*(9), 175-177.

Lindmark, M. (2002). An EKC-pattern in historical perspective: Carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870-1997. *Ecological Economics*, *42*(1–2), 333–347.

List, J. A., & Gallet, C. A. (1999). The environmental Kuznets curve: does one size fit all?. *Ecological economics*, *31*(3), 409-423.

Liu, X. (2005). Explaining the relationship between CO2 emissions and national income—The role of energy consumption. *Economics Letters*, *87*(3), 325-328.

Martínez-Zarzoso, I., & Bengochea-Morancho, A. (2004). Pooled mean group estimation of an environmental Kuznets curve for CO2. *Economics Letters*, *82*(1), 121–126.

Omri, A. (2013). CO2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. *Energy Economics*, *40*, 657–664.

Omri, A., Nguyen, D. K., & Rault, C. (2014). Causal interactions between CO2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Economic Modelling*, *42*, 382–389.

Ongan, S., Isik, C., & Ozdemir, D. (2021). Economic growth and environmental degradation: evidence from the US case environmental Kuznets curve hypothesis with application of decomposition. *Journal of Environmental Economics and Policy*, *10*(1), 14-21.

Pablo-Romero, M. D. P., & Sánchez-Braza, A. (2017). Residential energy environmental Kuznets curve in the EU-28. *Energy*, *125*, 44-54.

Pacala, S., & Socolow, R. (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science*, *305*(5686), 968-972.

Pao, H. T., & Tsai, C. M. (2010). CO2 emissions, energy consumption and economic growth in BRIC countries. *Energy Policy*, *38*(12), 7850–7860.

Plassmann, F., & Khanna, N. (2006). Preferences, Technology, and the Environment: Understanding the Environmental Kuznets Curve Hypothesis. *American Journal of Agricultural Economics*, *88*(3), 632–643.

Prema, V., & Rao, K. U. (2015). Development of statistical time series models for solar power prediction. *Renewable Energy*, *83*, 100-109.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F.,... & Foley, J. A. (2009). A safe operating space for humanity. Nature, 461(7263), 472-475.

Atasoy, B. S. (2017). Testing the environmental Kuznets curve hypothesis across the US: Evidence from panel mean group estimators. Renewable and Sustainable Energy Reviews, 77, 731–747.

Selden, T. M., & Song, D. (1994). Environmental quality and development: is there a Kuznets curve for air pollution emissions? Journal of Environmental Economics and Management, 27(2), 147-162.

Atasoy, B. S. (2017). Testing the environmental Kuznets curve hypothesis across the US: Evidence from panel mean group estimators. *Renewable and Sustainable Energy Reviews*, *77*, 731-747.

Shafik, N. (1992). Economic Growth and Environmental Quality: Time series and cross-country evidence (Policy Research Working Paper No. 904). The World Bank.

Shahbaz, M., Shafiullah, M., Papavassiliou, V. G., & Hammoudeh, S. (2017). The CO2–growth nexus revisited: A nonparametric analysis for the G7 economies over nearly two centuries. *Energy Economics*, *65*, 183-193.

Shahbaz, M., Solarin, S. A., Hammoudeh, S., & Shahzad, S. J. H. (2017). Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. *Energy Economics*, *68*, 548-565.

Soytas, U., Sari, R., & Ewing, B. T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecological Economics*, *62*(3-4), 482-489.

Steffen, W., Crutzen, P. J., & Mcneill, J. (2008). Earth System Governance Project View project Systems approach towards sustainable cities View project. *36*(8), 614–621.

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development*, *32*(8), 1419–1439.

Stern, D. I., & Common, M. S. (2001). Is there an environmental Kuznets curve for sulfur? Journal of Environmental Economics and Management, 41(2), 162-178.

Taguchi, H. L. (2012). A diffractive and Deleuzian approach to analysing interview data. *Feminist Theory*, *13*(3), 265–281.

Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy*, *37*(1), 246–253.

Tang, S., Andres, B., Andriluka, M., & Schiele, B. (2015). Subgraph decomposition for multi-target tracking (In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition), Boston, USA.

Tapia Granados, J. A., & Carpintero, Ó. (2013). Economic aspects of climate change. *Journal of Crop Improvement*, *27*(6), 693-734.

Tessier, T. H., & Armstrong, J. S. (2015). Decomposition of time-series by level and change. *Journal of Business Research*, *68*(8), 1755-1758.

Wang, B., Yan, C., Iqbal, N., Fareed, Z., & Arslan, A. (2022). Impact of human capital and financial globalization on environmental degradation in OBOR countries: Critical role of national cultural orientations. *Environmental Science and Pollution Research*, *29*(25), 37327-37343.

Yilanci, V., & Ozgur, O. (2019). Testing the environmental Kuznets curve for G7 countries: evidence from a bootstrap panel causality test in rolling windows. *Environmental Science and Pollution Research*, *26*, 24795-24805.