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SHORT RESEARCH AND DISCUSSION ARTICLE

Energy mix outlook and the EKC hypothesis in BRICS countries: a perspective of economic freedom vs. economic growth

Seyi Saint Akadırı[1] · **Andrew Adewale Alola**[2,3] · **Ojonugwa Usman**[4]

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Abstract

This study attempts to unveil an additional dimension to economic freedom within the framework of the environmental Kuznet curve (EKC) hypothesis using the panel data for BRICS (Brazil, Russia, India, China, and South Africa) economies over the period 1995–2018. Firstly, the study found that the EKC hypothesis is valid only in the long run for the panel countries. Secondly, we found that economic freedom mimics the pattern of economic output. Thus, when economic freedom is employed in lieu of economic growth, the EKC hypothesis is also validated only in the long run. Importantly, when both economic freedom and output are employed alongside, they produce the same carbon mitigation effect in each of the short-run and long-run periods. Thirdly, the country-specific evidence of the role of economic freedom and output in environmental quality is not less of a *U*-shaped relationship in the short run. Lastly, the impact of the bloc's energy mix (coal, natural gas, and oil energy utilization) on environmental quality is undesirable in both the short and long run; only in South Africa natural gas has the potential to mitigate carbon emissions. Overall, the study offers relevant policy measures for attaining Sustainable Development Goals (SDGs) target to combat climate change and its impacts.

Keywords Economic freedom · Economic growth · BRICS · EKC hypothesis

JEL Classification C23 · 013 · Q42

Introduction

Economic freedom (EFR) can be described as the fundamental right of humans to control and dominate his or her own property or labor. In a free market, people have the freedom to produce, work, invest, and consume in a way or manner they prefer, can afford, or desire as long as such actions do not violate the rights of others. In addition, the government in such an economy grants goods, capital, and labor-free movement and desists from constraint or coercion of freedom beyond the length required to maintain and protect freedom itself. Many authors have examined the impact of some of the components of EFR on environmental responsibility (Young and Makhija 2014; Kinderman 2012; Ioannou and Serafeim 2012)[1] while Heckelman (2000) examined the causal nexus between EFR and EG. Thus, it is paramount to say that EFR could directly and indirectly affect CO_2 emissions via its impact on economic growth.

Following the study of Wood and Herzog (2014) which seeks to improve on their model and validate the assertion that economic freedom is significant in reducing domestic environmental issues, revealed that EFR has inversely impacted on

Responsible Editor: Roula Inglesi-Lotz

✉ Andrew Adewale Alola
aadewale@gelisim.edu.tr

Seyi Saint Akadırı
ssakadiri@cbn.gov.ng

Ojonugwa Usman
usmanojonugwa@gmail.com

1 Research Development, Central Bank of Nigeria, Abuja, Nigeria

2 Department of Economics and Finance, Istanbul Gelisim University, Istanbul, Turkey

3 Department of Financial Technologies, South Ural State University, Chelyabinsk, Russia

4 School of Business Education, Federal College of Education (Technical), Potiskum, Yobe State, Nigeria

[1] Usman et al. (2019) examined how democracy, a component of economic freedom, affects the environment in India.

Table 1 Statistical properties of the variables

	Carbon emissions	Output	Economic freedom	HDI	Coal	Natural gas	Oil
China							
Mean	6370.351	5.02E+12	53.080	0.659	1355.977	81.869	376.06
Maximum	9428.712	1.09E+13	57.800	0.758	1969.073	243.333	641.212
Minimum	3029.073	1.48E+12	51.000	0.549	665.249	15.374	163.385
Std. Dev.	2539.039	3.01E+12	1.817	0.069	531.231	69.994	151.792
Jarque-Bera	2.822	2.204	10.123A	1.973	2.990	3.044	1.777
Brazil							
Mean	366.456	1.91E+12	57.046	0.710	13.940	19.108	111.120
Maximum	504.610	2.42E+12	63.400	0.761	17.625	36.919	145.667
Minimum	251.917	1.38E+12	48.100	0.651	11.110	4.497	81.479
Std. Dev.	76.890	3.73E+11	4.110	0.035	1.923	10.585	20.314
Jarque-Bera	2.093	2.560	0.925	1.272	2.164	1.657	2.464
India							
Mean	1446.072	1.46E+12	52.167	0.553	256.810	33.117	145.630
Maximum	2479.072	2.82E+12	56.200	0.647	452.221	51.837	239.051
Minimum	774.466	6.50E+11	45.100	0.463	140.294	15.544	77.200
Std. Dev.	539.029	6.59E+11	3.052	0.059	100.950	12.070	46.341
Jarque-Bera	2.136	2.063	2.529	1.668	2.313	2.160	1.383
Russia							
Mean	1506.127	1.32E+12	51.721	0.761	98.217	344.953	138.550
Maximum	1617.810	1.74E+12	58.200	0.824	119.376	390.800	157.409
Minimum	1445.345	8.13E+11	48.600	0.701	83.930	296.998	125.212
Std. Dev.	46.685	3.39E+11	2.255	0.042	8.912	25.633	10.857
Jarque-Bera	1.325	2.691	12.399A	1.778	1.838	1.464	2.700
South Africa							
Mean	394.847	3.37E+11	63.271	0.653	82.316	2.502	25.124
Maximum	448.905	4.30E+11	67.100	0.705	93.824	3.911	28.615
Minimum	326.864	2.33E+11	60.700	0.610	71.247	0.799	20.745
Std. Dev.	44.812	6.82E+10	1.331	0.031	7.593	1.252	2.325
Jarque-Bera	2.810	2.279	9.714	2.001	1.872	3.330	1.938

"A" is the 1% statistical significance level

HDI Human Development Index, *Std.Dev* standard deviation

CO_2 emissions of over 100 countries between the period 2000 and 2010 when economic growth (EG) is at level, specifically in the short run. The fact remains that, Wood and Herzog (2014) used a dataset that came from large numbers of different countries for many years. These differences caused by unobservable factors could influence the results of the relationship between economic freedom and environmental pollution. In order to address this issue, we used the dataset of the fast-growing economic hub in the emerging markets. These countries as a well-known economic bloc include Brazil, Russia, India, China, and South Africa (henceforth called BRICS). In light of this development, we augment EFR in the environment Kuznets curve (EKC) equation (see the "Results and discussion" section). Then, we estimate the relationship between EFR and CO_2 emissions alongside some major primary energy sources, such as coal, natural gas, and oil consumption. Furthermore, we replaced EFR for EG in the EKC equation to confirm whether EFR can be used as a proxy for EG, using a more recent annual frequency dataset in a panel study between the period 1995 and 2018. For empirical analysis, we employ the autoregressive distributed lag model (ARDL) that generates both short-run and long-run estimates and does not impose restrictions on coefficients.

The contributions of this study are as follows: (a) this is the first study to augment EFR in the EKC model and confirm that EFR reacts to EG at level, than when EG is doubled both in the short and long run; (b) we validate that EFR can be a proxy for economic growth, as they are made up of similar components and produced similar results. The remaining sections of this study are outlined as follows: the "Data and method" section discusses the data and methodology. The "Results

Table 2 The model with both OUTPUT and EF

Estimate	Short-run	Long-run
OUTPUT	− 12.226^{C}	0.464^{A}
OUTPUTsq	0.221^{C}	− 0.010^{A}
EFR	− 0.030^{B}	0.074^{A}
COAL	0.080^{C}	0.811^{A}
NGAS	0.124	0.046^{A}
OIL	0.181	0.266^{A}
ECT (− 1)	− 0.560^{A}	

^{A}, ^{B}, and ^{C} denote the statistical significance at 1%, 5%, and 10%, respectively. The selected model is ARDL (2, 1, 1, 1, 1, 1, 1). The OUTPUT, OUTPUTsq, EFR, EFRsq, COAL, NATURAL GAS, and OIL are the respective logarithms of economic growth, economic growth square, economic freedom, square of economic freedom, coal consumption, natural gas consumption, and oil consumption, respectively

and discussion" present results and discuss findings, while the "Conclusion" section concludes the study.

Data and method

Description of dataset

In this study, we examined the role of the main primary energy consumption on environmental degradation for BRICS countries. The primary energy sources employed in the study are coal consumption (coal: measured in million tonnes oil equivalent), natural gas consumption (natural gas: measured in million tonnes oil equivalent), and oil consumption (oil: measured in million tonnes oil equivalent). The gross domestic Product (proxy as output) is measured in constant 2010 USD while economic freedom[2] is quantitatively and qualitatively measured from 12 classified main indicators. In addition, the data for the energy mix and carbon dioxide (CO_2) emissions are all retrieved from the British Petroleum, BP (2020) while the economic freedom, Human Development Index (HDI), and GDP series are retrieved from heritage.org (Heritage, 2020) and World Bank Development Indicator (WDI, 2019). CO_2 emissions are measured in millions of metric tonnes. İn order to account for the unexplained factors especially in the robustness tests, the Human Development Index is employed alongside other explanatory variables in each estimation procedure. In general, a balanced dataset for the period 1995–2018 is employed, and the descriptive statistics for each country is illustrated in Table 1.

[2] The index of economic freedoom considered a comprehensive perspective of all aspects of economic freedom. İn quantifying economic freedom index through a ranging method, the following 12 main perspectives were explored: rule of law, government size, regulatory efficiency, market openness, properrty right, judicial effectiveness, government integrity, fiscal health, labor freedom, monetary freedom, financial freedom, and investment freedom. Additional information is available at https://www.heritage.org/index/about.

Methods

Given the preliminary work of Kuznets (1955) on the economic growth-environment nexus, the concept has been widely discussed under different frameworks (Stern and Common 2001; Stern 2004; Apergis and Ozturk 2015). Moreover, the current context employs the environmental Kuznets curve to reveal the applicability of economic freedom as well as

Table 3 The long-and short-run impact with ARDL estimate

Variables	Short-run coefficient	Long-run coefficient
Output (panel A)		
OUTPUT	− 9.901^{C}	0.425^{A}
OUTPUTsq	0.179^{C}	− 0.009^{A}
COAL	0.142	0.803^{A}
NATURAL GAS	0.128	0.049^{A}
OIL	0.191	0.286^{A}
Adjustment Parameter	− 0.511^{B}	C = − 1.651^{B}
Robustness		
OUTPUT	− 13.572^{C}	0.657^{A}
OUTPUTsq	0.247^{C}	− 0.013^{A}
COAL	0.203^{A}	0.783^{A}
NATURAL GAS	0.131	0.032^{A}
OIL	0.189^{C}	0.266^{A}
HDI	0.043	− 0.001
Adjustment parameter	− 0.452^{A}	C = − 3.118^{A}
EFR (panel B)		
EFR	− 2.125	0.920^{A}
EFRsq	0.256	− 0.102^{A}
COAL	0.361^{A}	0.736^{A}
NATURAL GAS	0.134	0.053^{A}
OIL	0.289^{B}	0.197^{A}
Adjustment Parameter	− 0.240	
Robustness		
EFR	− 4.704	1.402A
EFRsq	0.574	− 0.204A
COAL	0.527A	0.431A
NATURAL GAS	0.151	0.053A
OIL	0.326B	0.564A
HDI	− 0.440	− 0.167
Adjustment parameter	− 0.056C	

Panel A: ^{A}, ^{B}, and ^{C} denote the statistical significance at 1%, 5%, and 10%, respectively. ARDL (1, 0, 0, 0, 0, 0, 0)

Panel B: ^{A}, ^{B}, and ^{C} denote the statistical significance at 1%, 5%, and 10%, respectively. ARDL with fixed (dependent, dynamic regressors lag) = (2, 1) explore its semplance properties of economic output. This method is different from Ndlovu and Inglesi-Lotz (2020).

In this context, the EFR is incorporated in the actual EKC model as one of the explanatory variables as shown in Eq. 2 before implementing EFR in lieu of output as shown in Eq. 3.

$$\text{CEM} = f\,(\text{OUTPUT}, \text{OUTPUTsq}, \text{EFR}, \text{COAL}, \text{NATURAL GAS}, \text{OIL}) \quad (1)$$

$$\text{CEM} = f\,(\text{OUTPUT}, \text{OUTPUTsq}, \text{COAL}, \text{NATURAL GAS}, \text{OIL}) \quad (2)$$

$$\text{CEM} = f\,(\text{EFR}, \text{EFRsq}, \text{COAL}, \text{NATURAL GAS}, \text{OIL}) \quad (3)$$

The pooled mean group estimation

After examining the stationarity of the variables, each of the aforementioned models 1 to 3 is estimated by employing the appropriateness of the pooled mean group (PMG) of the autoregressive distributed lag (ARDL) (Pesaran et al. 1999). The PMG estimation is advantageous because it provides both the long-run and short-run inferences (Baloch et al. 2020). In this study, the step-by-step and detailed estimation procedures of the unit roots and the PMG are not provided because of space constraint. However, the results for the above models are provided in Tables 2, 3, and 4.

Results and discussion

In the first approach where economic freedom is employed alongside the economic output, the EFR observably mimics the directional pattern of economic output in both the short and long run (see Table 2). In this case, economic expansion exhibits a carbon emission mitigation effect in the short run just as economic freedom is found to have a similar desirable trend. However, the result reveals that the square of economic expansion (output) is detrimental to the BRICS' environmental quality, thus a *U*-shaped relationship between economic growth and environmental degradation is established in the short run. This implies that the short-run evidence in the current study affirms the non-validity of the EKC hypothesis for the BRICS economies as demonstrated by Tamazian et al. (2009) and Aydin and Turan (2020). Notwithstanding, the current study validates the EKC hypothesis in the long run which is in tandem with the results of the previous studies (Dong et al. 2017; Haseeb et al. 2018; Balsalobre-Lorente et al. 2019; Aziz et al. 2020).

Furthermore, the estimation without the EFR in the model as depicted in Eq. 2 also revealed a *U*-shaped (in short run) and an inverted *U*-shaped (in long run) relationship between the output and carbon emissions (see panel A of Table 3). However, upon the implementation of the last model where EFR is employed in lieu of economic expansion, a similar result as that of the output model is revealed (see panel B of Table 3). In specific, economic freedom triggers carbon mitigation in the short run, but a reverse result is found for the square of economic freedom in the same term. Thus, in the short-run, there is a *U*-shaped relationship between economic freedom and environmental degradation. However, in the long run, the result affirms an inverted *U*-shaped relationship, thus validating the EKC hypothesis from the perspective of economic freedom in the panel of BRICS economies.

Moreover, the robustness check in the lower part of panels A and B of Table 3 further reveals the semplance pattern of both economic output and economic freedom. In both the short and long run, the robustness check affirms the aforementioned results. Similarly, the country-specific short-run evidence in Table 4 further affirms the *U*-shaped relationship for the case of output and also the case of economic freedom. In addition, the study finds that coal consumption, natural gas consumption, and oil (fossil) energy consumption are all found to worsen the environmental quality for the panel of BRICS economies (see Tables 2 and 3). As regards the energy consumption in these countries, we observe that natural gas among other components of energy mix, promotes

Table 4 PMG-ARDL (cross-section/short-run) estimate

Estimate	OUTPUT	OUTPUTsq	COAL	NGAS	OIL	ect (− 1)
Brazil	− 20.10	0.357^{A}	0.155^{A}	0.118^{A}	0.654^{A}	-0.01^{A}
Russia	− 3.708	0.067^{A}	0.253^{A}	0.506^{A}	0.309^{A}	-0.01^{A}
India	− 3.785	0.068^{A}	0.323^{A}	0.040^{A}	0.117^{A}	-0.45^{A}
China	− 20.102	0.357^{A}	0.155^{A}	0.118^{A}	0.654^{A}	-0.01^{A}
South Africa	− 29.552	0.555^{A}	0.002	-0.023^{A}	0.034^{A}	
	EFR	EFRsq	COAL	NGAS	OIL	ect (− 1)
Brazil	− 3.090	0.376	0.159^{A}	0.121^{A}	0.750^{A}	-0.01^{A}
Russia	− 2.894	0.368^{B}	0.253^{A}	0.513^{A}	0.316^{A}	-0.01^{A}
India	− 0.132	0.014	0.215^{A}	0.033^{A}	0.089^{A}	-0.58^{A}
China	− 20.102	0.357^{A}	0.155^{A}	0.118^{A}	0.654^{A}	-0.01^{A}
South Africa	− 7.793	0.934	0.427^{A}	-0.003^{A}	0.116^{A}	-0.50^{A}

The 1%, 5%, and 10% statistically significant levels are respectively presented as ^{A}, ^{B}, and ^{C}. EFR, EFRsq, and ECT (− 1) are respectively the economic freedom, square of economic freedom, and the error correction term.

environmental quality only in South Africa. Lastly, a series of diagnostic tests in Tables 2 and 3 provide credence to the estimation techniques and results.

Conclusion

This study presents a novel perspective of testing the EKC hypothesis within the framework of economic growth and economic freedom for the panel of the BRICS economies. In the first approach, the study revealed the existence of the EKC hypothesis only in the long-run while affirming that the main energy mix (coal, natural gas, and oil energy consumption) is all detrimental to the bloc's environmental quality. In the second approach, economic freedom is incorporated in the output model, and such economic freedom is found to mimic economic output both in the short and long run. Importantly, the third approach is accomplished by employing economic freedom instead of output in the framework of the EKC. In this case, the established result is similar to the first approach where the EKC is validated only in the long run. Similarly, the result further posited that the energy mix in the examined panel BRICS countries is harmful to environmental quality. The policy implication for these findings is that the BRICS countries need to promote economic freedom through the approaches of economic, trade, and other sectoral integrations in order to sustain the gains of a sustainable environment among other benefits, even though economic freedom mimics output growth, our finding suggests the need to adapt an alternative and clean energy system to sustain a stable EKC for BRICS countries in both the short and long-run, respectively. Similarly, to sustain the bloc's drive toward environmental sustainability, there should be an increase in research and development, especially in renewable energy, energy innovations, and technologies since the increase in pollution is mainly attributed to the energy mix outlook in BRICS countries.

Authors contributions Seyi Akadiri is responsible for the study development.

Andrew Alola sourced for data, methodology, and estimations.

Ojonugwa Usman is responsible for the empirical discussion.

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Data Availability We sourced all data from the British Petroleum, BP (2020) heritage.org (Heritage, 2020), and World Bank Development Indicator (WDI, 2019).

Compliance with ethical standards

Ethical approval Authors mentioned in the manuscript have agreed for the authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

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