Resources Policy 75 (2022) 102472

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

Volatility in natural resources prices and economic performance: Evidence from BRICS economies

Jun Wen [a], Nafeesa Mughal [a,*], Maryam Kashif [b], Vipin Jain [c], Carlos Samuel Ramos Meza [d], Phan The Cong [e]

[a] School of Economics and Finance, Xian Jiaotong University, Shaanxi, China
[b] Department of Management Sciences, COMSATS Attock Campus, Pakistan
[c] Teerthankar Mahaveer University Moradabad, Uttar Pradesh, India
[d] CENTRUM Católica Graduate Business School (CCGBS), Pontificia Universidad Católica del Perú (PUCP), Perú
[e] Thuongmai University, Hanoi, Viet Nam

ARTICLE INFO

Keywords:
Natural resources price volatility
Economic performance
Oil rents
Natural gas rents
Green innovation

ABSTRACT

Natural resources and economic growth nexus have been extensively investigated since the last three decades and still the debate is in progress. However, in the current times, natural resources prices volatility got importance as natural resources prices are playing crucial role in economic growth by regulating economic activities, which is relatively less studied. Natural resources price volatility and economic performance nexus have set new trends for scholars and policy-makers. Volatility in natural resources could have a detrimental impact on the economic performance of a country or region. In this regard, the current study aims to identify the relationship between them while considering the role of green innovation in the BRICS economies between 1990 and 2021. Employing the cross-sectionally augmented autoregressive distributive lags (CS-ARDL) approach, the results revealed that natural resource volatility, oil rents, natural gas rents, and green innovation positively influence the economic performance in both short-run and long-run. These results are found robust as verified by the long-run estimator augmented mean group (AMG). Besides, the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneous test unveil a bidirectional causal association between the under discussion variables and economic performance. Based on the empirical findings, this study recommends that natural resources hedging, price freezing or ceiling, and promoting green innovation could be remedial measures to improve economic performance further and reduce natural resources price volatility in the region.

1. Introduction

Since 1970, the world has witnessed substantial global shifts in natural resources, which have relatively long lasting effects, particularly on the economic conditions of various countries and regions. One of the significant events was the 1973 global oil price shock, which caused world GDP and carbon dioxide (CO2) emission to diverge from an economic standpoint. After then, the widespread reliance on fossil energy and the world's ever-increasing energy demands began to pose a dilemma that might trap the world (Hoxtell and Goldthau, 2012; Aguirre and Ibikunle, 2014). This trap needed a comprehensive and multifaceted global solution. As a result of this pressure, the 1992 Rio summit brought in a major shift in attitudes about economic growth and the mainstreaming of environmental problems into economic agendas.

In the early 1990s, there was a heated discussion among academics and policymakers about whether natural resources are beneficial or harmful to economic growth and development. Natural resources, according to Gylfason and Zoega (2006), Gelb (1988), Sachs and Warner (2001), are harmful for an economy's health since their abundance slows down the growth process compared to economies having scares resources – natural resources curse. However, the recent literature claimed that natural resources are significant factors of economic growth – enhances economic activities and promote growth (Guan et al., 2021; Sun and Wang, 2021). Besides, some researchers claimed that natural resources curse could be converted into resources blessings by enhancing human capital, improving institutional quality, and product

* Corresponding author.
E-mail addresses: Wjun1972@163.com (J. Wen), nafeesamughal@stu.xjtu.edu.cn (N. Mughal), maryamkashif82@gmail.com (M. Kashif), vipin555@rediffmail.com (V. Jain), Carlos.Ramosm@pucp.pe (C.S. Ramos Meza), congpt@tmu.edu.vn (P.T. Cong).

https://doi.org/10.1016/j.resourpol.2021.102472
Received 3 September 2021; Received in revised form 3 November 2021; Accepted 12 November 2021
Available online 26 November 2021

diversification (Epo and Nochi Faha, 2020; Joya, 2015; Leong and Mohaddes, 2011). Undoubtedly, many factors and indicators influence the economic performance of the country. However, few factors attract the attention of researchers and policymakers regarding economic performance. In this regard, studies have provided contradictory results regarding the impact of natural resources and natural resources abundance on economic performance (Hayat and Tahir, 2021; Rahim et al., 2021; Pérez and Claveria, 2020) and financial development (Atil et al., 2020) of the country or regions.

In recent times, after the Covid-19 pandemic, volatility in the natural resources price has gained the policy-makers and governors' attention regarding its impact on economic performance and sustainability. In this concern, studies have empirically analyzed the destructive influence of natural resource price volatility on the country's economic performance (Guan et al., 2021; Chien et al., 2021; Atil et al., 2020; Gong et al., 2020; Khan et al., 2020). The focus is biased towards the oil prices volatility as it is considered one of the most tradable goods globally. Thus, empirical studies concluded that the oil price volatility negatively affect economic growth (Lin et al., 2020; Gkillas et al., 2020; Nonejad, 2020). Nonetheless, there are many studies that investigates the nexus of natural resources volatility and economic performance, Still, there is a massive gap in the literature regarding natural resources price volatility and economic performance. Specifically, the earlier mentioned studies have empirically investigated oil price volatility and its connection with stock market while ignoring the association of natural resources price volatility in economic performance. Therefore, current research intended to attract the attention of academics and policymakers to this emerging issue, empirical outcomes and policy implications of which help governors overcome the natural resources price volatility and its association with economic performance. Besides natural resource price volatility, factors such as oil rents, natural gas rents, and green innovation could also influence the country's economic performance. Many studies have provided evidence that oil rents and natural gas rents have a significant contribution to the region's economic growth (Adedoyin et al., 2020; Etokakpan et al., 2020). However, regarding green technological innovation, studies have empirically illustrated that green innovation development leads to a win-win situation regarding environmental and economic sustainability (Raza, 2020; Yuan and Zhang, 2020).

The main objective of this research is to empirically investigate the relationship of natural resources price volatility on the economic performance of BRICS economies. As the recent global pandemic outbreak substantially impacted every economic and non-economic sector, thus the natural resources market has also been analyzed as fluctuating. Therefore, it is important to investigate the impact of natural resource price volatility on the economic performance of some of the high energy importing countries. Secondly, this paper aims to investigate the influence of oil rents and natural gas rents on the economic performance of the selected region. As both oil and natural gas rents could play essential role in the development of an economy: therefore, it is important to investigate this relationship in the Covid-19 pandemic. Lastly, this research study aims to identify the association between green innovation and economic performance. Where the earlier research provides a positive influence on environmental sustainability. However, there is a need of research on the economic impact of green innovation. Since the objective of this research is innovative, this may provide a new path for the academic world towards the empirical investigation of natural resources volatility and its nexus with economic performance. Various developed and developing countries across the globe is facing the issue of volatility due to many reasons, including global or eternal shocks, demand and/or supply shocks, among others. Therefore, this research may play as a pioneering role for investigating such issue.

Since the last three decades, the scholars brought an innovation in the traditional concept about positive role natural resources and its abundance in economic growth. Particularly, the scholars argued that natural resources and its abundance weakens economic growth of the resource's rich economies (Gylfason and Zoega, 2006; Sachs and Warner, 2001; Gelb, 1988). However, this statement has been challenged by recent studies (Epo and Nochi Faha, 2020; Joya, 2015; Leong and Mohaddes, 2011). Since this connection has been extensively studied. Yet there are limited studies that empirically investigate volatility in natural resources and its nexus to economic performance. This motivates the scholars to pay attention towards this critical nexus. Therefore, the motivation of this study is that to provide empirical estimates for natural resources volatility and economic performance nexus in case of BRICS economies.

This study is novel and its contribution to the existing literature is threefold. Firstly, it is one of the pioneering studies that considers natural resources prices volatility and economic performance while using an extended dataset covering the Covid-19 pandemic period. Nevertheless, the recent studies of Ma et al. (2021), Sun and Wang (2021) investigated natural resources volatility and economic performance nexus. However, these studies only intended towards the causal association of these variables. While this contributes to the literature by providing empirical evidence of the influence of each explanatory variable. Secondly, this study is the pioneering study that empirically investigates the impact of natural resource price volatility in the group of both emerging and developing nations, i.e., BRICS economies. Since, various economic and environmental factors are investigated for this region. However, this study intended to provide empirics regarding natural resources prices volatility in the region, which is relatively unexplored area. Thirdly, this study considers the role of green innovation on economic performance. As most of the studies have empirically investigated the said variable from an environmental perspective. However, green innovation could not only be limited to the environment, but its economic impact should also be disclosed, which the existing literature is lacking.

The rest of the paper is arranged as follows: Section-2 provide relevant review of literature that covers the existing literature for all the variables under consideration; Section-3 represents model specification, data and methodology used for empirical investigation of the data; Section-4 provides results and discussion of the obtained estimates; finally, Section-5 presents the concluding remarks and policy implications based on the empirical findings.

2. Review of literature

Existing literature provides evidence about the nexus of natural resource price volatility and economic performance. Scholars and policymakers have provided extensive literature concerning natural resource price volatility and economic growth, where most of the influence of natural resource price volatility is found negative. However, natural gas and green innovation has also been widely investigated for various countries and regions. A detailed review of relevant literature has been provided in this section of the paper.

Guan et al. (2021) investigated natural resource dependent countries to identify natural resource price volatility on economic performance and growth between 2000 and 2020 period. The study used autoregressive distributed lags (ARDL) and the pooled mean group (PMG) model and concluded that events greatly affect natural resources. That is global financial crisis and Covid-19 significantly downturn the crude oil market severely than the gold market. The study concludes that volatility in the natural resources significantly reduces economic growth in the long-run. Similarly, Hayat and Tahir (2021) examined three resource-rich economies over the period of 1960–2016. The study used ARDL approach and conclude that although natural resources significantly contribute to economic growth. However, natural resources volatility adversely affects economic growth in UAE, Saudi Arabia and Oman. In contrast to the prior study, Rahim et al. (2021) found that natural resource rents significantly impede economic growth in the Next-11 countries between 1990 and 2019. However, development of human capital could play critical role in stimulating the positive impact of natural resources in economic growth. Similarly, Pérez and Claveria

(2020) unveils that factors such as corruption, which does not allow natural resource rents to contribute to economic growth in mineral dependent African economies between 2007 and 2016.

In continuation, most of the recent studies have empirically analyzed the influence of natural resource such as crude oil price on the economic growth and its indicators. In this regard, Atil et al. (2020) analyzed oil prices, economic growth, and financial development in case of Pakistan throughout 1972–2017. Using the long-run co-variability approach, the empirical results asserted that natural resources are blessing to financial development. Also, the oil prices are found to have a substantial effect on financial development. Chien et al. (2021) examined the volatility of crude oil prices and economic growth nexus in Pakistan covering 1980–2018 period. Using ARDL approach, the study conclude that oil prices negatively affect the whole economic sector of the country. However, positively influence only the communication and transportation sectors. Concerning mixing frequencies, Gong et al. (2020) uncovered that economic growth, inflation, and trade volume significantly and adversely affect oil price volatility. However, the oil price volatility significantly affects these macroeconomic indicators in return.

In case of seven low-income oil-importing sub-Saharan African (SSA) countries, Akinsola and Odhiambo (2020) examined the relationship between oil prices and economic growth. The study uses non-linear ARDL and PMG approaches and conclude that the oil prices volatility does not significantly affect economic growth in the short-run, but significant impact in the long-run. In addition, the study reveals that the oil price decrease promotes economic growth and oil price increase adversely affect economic growth. Baba (2020) investigated the nexus between oil price volatility and economic growth in Nigeria from 1997 to 2017. Based on the vector autoregressive approach, the study reveals that oil price volatility significantly reduces economic growth, household welfare, and enhances poverty ration in the region. Moreover, Maheu et al. (2020) empirically investigated the volatility link between economic growth and oil price shock and conclude that there is a robust link among oil price shock and economic growth. Concerning environmental impact of the oil price volatility, Mohamued et al. (2021) discovered that oil price volatility showed asymmetric impact on the environmental conditions of oil-importing and oil exporting economies.

Natural resources are not only limited to the crude oil and other minerals such as gold, but also include natural gas, which does have a significant influence on both environment and economic growth. In this concern, Etokakpan et al. (2020) investigated Malaysia between 1980 and 2014 by using cointegration and Granger causality test. The estimated results reveal that natural gas on the one hand contributes to economic growth, but also promote environmental degradation. Similar results have also been found by Topcu et al. (2020) for 124 countries throughout 1980–2018 period. The authors revealed that energy consumption and natural resources played a significant role in attaining higher economic growth in these countries. In continuation, Galadima and Aminu (2020) utilized non-linear ordinary least square (NOLS) methodology and demonstrates that natural gas consumption boosts economic growth in the region. However, this relationship is found non-linear. Besides, Magazzino et al. (2021) identified a bidirectional causal association between natural gas and economic growth in Japan and Germany throughout 1970–2018. In contrast, Rafindadi and Ozturk (2015) demonstrates that there is an indirect influence of natural gas consumption on the economic performance Malaysia. However, the economic growth of country does not cause natural gas consumption.

Concerning environmental related technological innovation, scholars provide extensive literature which is termed as green innovation. In this regard, the most recent study of Zhang and Ma (2021) analyzed the mediating role of green innovation on 246 Chinese firm's economic performance. Using multiple regression analysis, the study unveils that green innovation facilitates the relationship between economic performance and environmental management breadth. However, the environmental leadership encourages the influence of environmental management depth on green innovation. Similarly, for the firms' sustainability in Malaysia, Bilan et al., 2020 used primary data techniques and concludes that leadership styles significantly promote organizational learning but does not contribute to the sustainability of firms. However, innovation could significantly play a moderating role between organizational learning and economic sustainability of the firm. Using a structural equation modeling technique, Raza (2020) conducted primary data research for short sea shipping industry and conclude that the regulatory pressure has engendered green innovation, which helps promote both environmental and economic performance in the industry. Hence, the green innovation consideration leads to win-win situation concerning both environment and economy.

In addition continuation, Caglar et al. (2021) investigated EU-5 economies concerning carbon neutrality by using novel unit root tests. The study uncovers that all the six components including carbon, cropland, grazing land, forest, built-up land, and fishing grounds holds unit root. In case of top-5 EU economies, Balsalobre-Lorente et al. (2021b) reveals that natural resources exhibit an inverted U-shaped influence on CO_2 emissions in the region. As mentioned earlier, natural resources could enhance economic growth. However, this economic growth is adversely affecting environmental quality by promoting climate change and environmental degradation (Leitão and Lorente, 2020). However, Leitão and Lorente (2020) revealed that renewable energy and trade openness are negatively affecting these factors – improving environmental quality. However, Balsalobre-Lorente et al. (2018) revealed that trade openness, and the interaction of renewable energy and economic growth significantly reduces CO_2 emission in the EU-5 economies throughout 1985–2016. The latter stance is supported by the study of Balsalobre-Lorente (2021a) that renewable energy reduces CO_2 emission in Greece, Italy, Portugal, and Spain. Still, an environmental Kuznets curve is valid for the region during the period 1995–2015. Further, Bilgili et al. (2021) used wavelet methodology and revealed that hydropower energy significantly reduces CO_2 emission by adversely affecting greenhouse gas emission. Unlike prior studies, Adedoyin provide evidence that coal rents are not increasing carbon emission in the BRICS economies between 1990 and 2014. Also, energy diversification could promote energy requirement in the global energy market. However, environmental sustainability is only possible by decoupling economic growth from CO_2 emission.

In case of 30 Chinese provinces, Yuan and Zhang (2020) examined the nexus between technological innovation, sustainable development and flexible environmental policy. The study uses data over the period from 2006 to 2015, the authors employed system generalized method of moment (sys-GMM). The results demonstrates that technological innovation and flexible environmental policies significantly promote sustainable development of industries. For the same country, Cao et al. (2020) conclude that technological innovation and resources consumption are both the critical mechanisms for environmental regulations that affect economic performance in the country. Zeraibi et al. (2020) identified the asymmetric association between technological innovation, energy consumption and economic growth in China throughput 1980–2018. The estimated results unveils that a decline in the energy consumption would significantly reduces economic growth in the region. However, the technological innovation could significantly promote economic growth. In consistency to the positive influence of technological innovation on economic growth, Zhou et al. (2020a) argued that with the increase in technological innovation, tax rate and growth rates would substantially increase. However, the public spending rate would significantly fall-down. In the same line, Zhou et al. (2020b) reveals that pollution abatement technological innovation will not only promote environmental quality, but also substantially contribute to economic growth. The recent study of Zeraibi et al. (2021) empirically investigated five Southeast Asian economies throughout 1985–2016 by using CS-ARDL approach. The study reveals that technological innovation and renewable energy generation capacity significantly reduces ecological footprints. Further, Balsalobre-Lorente et al. (2019) demonstrated that regulatory energy policies that are linked with the energy innovation process and pollution intensive resources replacement are leading indicators of environmental quality improvement.

3. Methodology

3.1. Data and model specification

Based on the objective, this study used a total of five variables where the dependent variable is gross domestic product (GDP). It is well known that GDP is the measure of an economy's health, which consider many economic factors and indicators such as consumption, investment, transaction, revenue, etc. Therefore, GDP is a substantial proxy for the representation of economic performance. Besides, there are four exogenous variables that this study used in an empirical investigation, including total natural resource rent (TNR) which represents volatility of the natural resources price in this case, oil rents (ORR), and natural gas rents (NGR). Besides, this study also considers the role of green innovation (GI) in economic performance, which is environmentally related technological innovation. Data for all of these variables have been obtained from two sources. Where the variables description and data sources are provided in Table-1. Data for all of the mentioned variables are obtained the covers the period from 1990 to 2021. The obtained data covers BRICS economies that include five countries, namely: Brazil, Russia, India, China and South Africa. The reason for selecting BRICS economies is that these economies are in alliance for various economic and developmental purposes. Primarily, these economies aim to promote development and cooperation, peace and security. [1] Therefore, any policy change in one country could have affect on other economy. However, a policy measure that describes the whole BRICS region could have a greater influence on the rest of developing as well as developed economies. Therefore, these countries are taken into consideration collectively.

Based on the objectives and literature as mentioned in the Section-2, this study allows four exogenous variables, including TNR, ORR, NGR, and GI. However, to identify the specific influence of exogenous variable on economic performance, an econometric approach is required. While an econometric approach could not be performed without constructing an econometric model, which clearly indicates dependent and explanatory variable. In this regard, current study constructed the following

Table-1
Variables' description and data sources.

Variable	Description	Data source
GDP	Gross domestic product, measured in constant US$ 2010 prices	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
TNR	The sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents and measured as a percent of GDP.	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
ORR	The difference between the value of crude oil production at regional prices and total costs of production and measured as a percent of GDP.	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
NGR	The difference between the value of natural gas production at regional prices and total costs of production and measured as a percent of GDP.	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
GI	Green Innovation is environment related technological innovation.	https://stats.oecd.org/#

[1] For details, visit https://www.gov.za/events/fifth-brics-summit-general-background.

Table-2
Slope heterogeneity and cross-section dependence.

Slope Heterogeneity Test	Statistics
$\tilde{\Delta}$	10.570***
$\tilde{\Delta}^{Adjusted}$	11.727***
Cross-Section Dependence	
GDP	**ORR**
16.382**	6.91***
TNR	**NGR**
9.652***	11.702***
GI	
0.954	

Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.

Table-3
Unit root testing (Pesaran, 2007).

Variables	Intercept and Trend	
	I(0)	I(1)
GDP	−1.847	−3.172***
ORR	−2.719	−4.132***
TNR	−3.027**	–
NGR	−3.136***	–
GI	−4.868***	–

Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%. I(0) is for level, and I(1) is for the first difference.

Table-4
CS-ARDL.

Short Run			
Variables	**Coefficients**	**Std. Error**	**Z-Statistic**
ORR	0.053***	0.0067	7.91
TNR	0.058***	0.0078	7.43
NGR	0.023***	0.0058	4.07
GI	0.085***	0.0088	9.68
ECM(-1)	−0.99***	0.1377	−7.25
Long Run			
ORR	0.064***	0.0089	7.19
TNR	0.063***	0.0193	3.26
NGR	0.024***	0.0058	4.18
GI	0.089***	0.0103	8.64

Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.

Table-5
Robustness test.

AMG			
Variable	Coefficients	Std. Error	Z-Statistic
ORR	0.091***	0.0203	4.48
TNR	0.209***	0.0505	4.13
NGR	0.015***	0.0043	3.53
GI	0.046***	0.0125	3.66
Constant	11.973***	0.2025	59.11

Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.

Table-6
Causality check.

Pairwise Dumitrescu Hurlin Panel Causality Tests			
Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
ORR → GDP	6.37793***	7.33783	0.000
GDP → ORR	5.09443***	4.40847	0.000
TNR → GDP	5.16836***	5.66351	0.000
GDP → TNR	5.79164***	4.39489	0.000
NGR → GDP	4.01356***	4.06499	0.000
GDP → NGR	3.77354***	3.73274	0.000
GI → GDP	5.50172***	3.79622	0.000
GDP → GI	4.98880***	5.41495	0.000

Note: Significance level is denoted by ***, ** and * for 1%, 5% and 10%.

general model:

Model

$$GDP_{it} = f(TNR_{it}, ORR_{it}, NGR_{it}, GI_{it})$$

where the general equation reveals that economic performance is a function of natural resources price volatility, oil rents, natural gas rents, and green innovation. However, the priorly mentioned model could be transformed into the regression model as following in Eq. (1):

$$GDP_{it} = \delta_0 + \delta_1 TNR_{it} + \delta_2 ORR_{it} + \delta_3 NGR_{it} + \delta_4 GI_{it} + \varepsilon_{it} \tag{1}$$

where in Eq. (1), GDP represents economic performance, TNR indicates natural resources price volatility, ORR denotes oil rents, NGR represents natural gas rents, and GI denotes green innovation. Besides, δ_0 denotes the intercept and δ_1, δ_2, δ_3, and δ_4 are the slopes of TNR, ORR, NGR, and GI, respectively. Additionally, ε_{it} denotes the error term of the regression models. While "i" and "t" in the subscript indicates cross-section and time-series, respectively.

3.2. Estimation technique

This study begins empirical estimation of the data under consideration by testing the slopes coefficient heterogeneity and cross-section dependence of the panel. Further, the study also examines the stationarity of time series of the presence of unit root across the time. This will lead us to adopt appropriate econometric approach for the specific influence of each exogenous variable on the BRICS economies' economic performance. Finally, the causal association between the dependent and independent variables have also been analyzed.

3.2.1. Slope heterogeneity and cross-section dependence

We begin the process of empirical estimation by analyzing the cross-section dependence and slope heterogeneity of the model. Since the emergence of industrial revolution particularly after 1840, trade and business reports rapid growth within the border and cross borders. The main reason behind is that the technical advancements or innovation brought about new methods of working and living, transforming society as a whole. Where this transformation leads to the production and manufacturing of more goods in less time. Besides, the goods and services demand from international communities also push international trade, which increase the dependency of one country on other countries. Moreover, countries across the globe are depending on each other for attaining various economic, financial, political, and environmental objectives. The interdependence across countries reveals that countries could show resemblance in some respects and diss-similarities in other aspects. However, in an econometric investigation, the homogenous characteristics of countries in the panel could provide biased and inefficient estimates, in this regard, we utilized the Pesaran and Yamagata (2008) slope coefficient homogeneity (SCH) test in order to test for the slope heterogeneity or homogeneity in the BRICS economies. The Pesaran and Yamagata (2008) SCH test provides estimated results both the SCH and adjusted SCH. Both the SCH and adjusted SCH could be calculated via the following formulation in Eq. (2) and Eq. (3), respectively:

$$\widehat{\Delta}_{SCH} = \sqrt{N(2k)^{-1}}\left(N^{-1}\acute{S} - K\right) \tag{2}$$

$$\widehat{\Delta}_{ASCH} = \sqrt{N}.\sqrt{\frac{T+1}{2K(T-K-1)}}\left(N^{-1}\acute{S} - 2K\right) \tag{3}$$

where $\widehat{\Delta}_{SCH}$ calculates the slope coefficient heterogeneity and $\widehat{\Delta}_{ASCH}$ estimates the adjusted slope coefficient heterogeneity across the panel. Furthermore, the Pesaran and Yamagata (2008) test assumes that the slopes coefficients are homogenous throughout the panel as null hypothesis. Whereas the null hypothesis could be rejected if the significant results are found for the said test.

As mentioned earlier, there are multiple factors that influence the dependence of one economy on other economies, therefore the issue of cross-section dependence is more common in the panel data. Moreover, the estimation could lead biased and inconsistent results in the presence of cross-section dependence (Campello et al., 2019). Therefore, this study utilized the Pesaran (2004) cross-section dependence (CD) test in order to empirically analyze the dependence of cross-sections between the BRICS economies. The said test considers that the cross-sections in the selected panel are independent as null hypothesis. That is, the null hypothesis designate that the cross-section of the panel does not depends upon each other by any means. However, if the estimated outcomes are found significant, it will allow us to reject the null hypothesis and accept that the cross-section dependence is present in the panel. The cross-section dependence via Pesaran (2004) CD test could be calculated by the following Eq. (4):

$$CD_{Test} = \frac{\sqrt{2T}}{[N(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik} \tag{4}$$

3.2.2. Testing stationarity

After investigating the slope heterogeneity and cross-section dependence of the panel, we further examine the stationarity of time series variable in the panel. Similar to the issues priorly discussed, if the time series of data under consideration is non-stationary throughout time, this will lead to biased and inconsistent estimates in an empirical examination. In this regard, we used the cross-sectionally augmented IPS (CIPS) approach proposed by Pesaran (2007). Prior to that, in order to avoid the issues created by cross-section dependency, Pesaran (2006) proposed a factor modelling technique whereby the cross-section averages are simply included to the model as a proxy for unobserved common components. Pesaran (2007) suggested a unit root test based on this method. To tackle the cross-section dependence issue, this technique enhances the Augmented Dickey-Fuller (ADF) regression with lagged cross-sectional mean and its first difference. This technique takes into account cross-section dependency and could be utilized when N > T and T > N are present. The cross-sectionally augmented Dickey-Fuller (CADF) regression is provided as following:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \overline{y}_{t-1} + d_1 \Delta \overline{y}_t + \varepsilon_{it} \tag{5}$$

where $\overline{y}_t$ represent the average of N observations. In order to avoid serial correlation, the regression must include the first differenced lags of both y_{it} and $\overline{y}_t$, which is provided as following:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \overline{y}_{t-1} + \sum_{j=0}^{n} d_{j+1} \Delta \overline{y}_{t-j} + \sum_{k=1}^{n} c_k \Delta y_{i,t-k} + \varepsilon_{it} \tag{6}$$

Afterwards, the Pesaran (2007) provides the average of t-statistics for each unit of cross-section ($CADF_i$) in the selected panel and delivers the CIPS estimates as provided in Eq. (7) below:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \tag{7}$$

This test assumes the null hypothesis as the presence of the unit root in the data. However, if the CIPS statistics exceeds the critical value, the null hypothesis of the unit root presence could be rejected.

3.2.3. Cross-sectionally augmented ARDL model

In order to analyze both the short-run and long-run coefficients, we utilized the cross-sectionally augmented autoregressive distributed lags (CS-ARDL) model proposed by Chudik and Pesaran (2015). The CS-ARDL is an efficient estimator as it provides robust estimates whether the data is stationary at level, first order, or both, and the series is cointegrated or not (Okumus et al., 2021). Since this ARDL belongs to the family of dynamic common correlated estimator (CCE) which considers the individual estimation with the dependent variable's lagged term and lagged cross-section averages, therefore the cross-sectional dependency has also been considered in this approach (Chudik and Pesaran, 2015). This technique allows the mean group estimation when slopes coefficients are not homogenous. As per Chudik et al. (2017), the CS-ARDL model's mean group version is based on supplementing the ARDL assessment of each cross-section with cross-sectional averages that are proxies for unobserved common variables and their lags. Moreover, the CS-ARDL also tackles the issue of weak exogeneity, which occurs when the lagged dependent variable has been included in the model (Okumus et al., 2021). The authors of the said approach also argued that augmentation of the lagged cross-section averages into the model mostly tackles the issue of endogeneity. The following regression can be used to get the CS-ARDL:

$$y_{i,t} = \theta_i + \sum_{l=1}^{n_y} \lambda_{l,i} y_{i,t-1} + \sum_{l=0}^{n_z} \beta_{l,i} x_{i,t-1} \sum_{l=0}^{n_\varphi} \varphi_{i,l}' \bar{z}_{i,t-l} + \varepsilon_{it} \tag{8}$$

where in Eq. (8) above, $\bar{z}_{i,t-l}$ indicates the lagged cross-section averages, i.e., $\bar{z}_{t-l} = \bar{y}_{i,t-l}, \bar{x}_{i,t-l}$. However, the long-run coefficients of the mean group could be estimated as following:

$$\vartheta_{CS-ARDL,\, i} = \frac{\sum_{l=0}^{nz} \widehat{\gamma}_{l,i}}{1 - \sum_{l=0}^{ny} \widehat{\lambda}_{l,i}}\ ,\ \vartheta_{MG} = N^{-1}\sum_{i=1}^{N} \widehat{\vartheta}_i \tag{9}$$

where in the above Eq. (9), $\widehat{\vartheta}_i$ represents each cross-section's individual estimations. Moreover, the error correction of the CS-ARDL estimator could be obtained via the following Eq. (10):

$$\Delta y_{i,t} = \omega_i \left[y_{i,t-l} - \widehat{\varphi}_i x_{i,t} \right] - \theta_i + \sum_{l=1}^{n_{y-1}} \lambda_{l,i} \Delta_l y_{i,t-1} + \sum_{l=0}^{n_z} \beta_{l,i} \Delta_l x_{i,t-1} \sum_{l=0}^{n_\varphi} \varphi_{i,l}' \bar{z}_{i,t-l} + \varepsilon_{it} \tag{10}$$

where ω_i indicates the error correction speed of adjustment. The CCE mean group estimator having augmented lags performs efficiently in the term such as power, size and bias (Chudik and Pesaran, 2013). On the other hand, the authors observed negative biased when 'T' is less than 50, i.e., T < 50. In order to tackle or avoid the biasedness od time series sample, Chudik and Pesaran (2015) proposed the split-panel jacknife approach presented by Dhaene and Jochmans (2015). This method could be performed as following:

$$\widetilde{\Pi}_{MG} = 2\widetilde{\Pi}_{MG} - \frac{1}{2}\left(\widehat{\Pi}^{a}_{MG} + \widehat{\Pi}^{b}_{MG}\right) \tag{11}$$

where $\widehat{\Pi}^{a}_{MG}$ and $\widehat{\Pi}^{b}_{MG}$ represents the CCEMG in the time dimension in the first half (t = 1, 2, …, (T/2)) and second half (t = (T/2) +1, (T/2) +2, (T/2) +3, …, T), respectively. In the present study, the considered time-span is 32 years (i.e., T, 50). Hence, the CS-ARDL bias corrected estimations will be provided in the study.

3.2.4. Robustness test

In order to verify or validate the findings of the earlier discussed estimator, i.e., CS-ARDL, we further utilize augmented mean group (AMG) estimator, developed by Eberhardt and Bond (2009) and Eberhardt and Teal (2010). This approach is an alternative to common correlated effect mean group (CCEMG) estimator proposed by Pesaran (2006). Specifically, in the CCEMG approach, the unobservable common factors' set could be treated as a nuisance. However, in this AMG estimating approach, the unobservable common factors' set could be treated as a common dynamic process, which further depends on the contest, and provide efficient estimates and interpretations (Sadorsky, 2014). According to Paramati and Roca (2019) this approach is robust when there is a cross-sectional dependence issue in the panel and provides efficient and reliable estimates. After analyzing the CS_ARDL and AMG models, we further perform the panel causality test that examines long-run causal relationship between the variables under consideration.

3.2.5. Pairwise dumitrescu hurlin panel causality tests

Two estimating approaches namely CS-ARDL and AMG identified the influence of each exogenous variable on the economic performance of BRICS economies. However, in order to analyze the causal relationship between the considered variables, we used the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneous test. Concerning the said test, it provides efficient estimates when the time series and cross-sections are not equal, i.e., T≠N. According to Banday and Aneja (2020), the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneous test provides efficient test by considering the cross-sectional dependency and slope coefficient heterogeneity issues.

4. Results and discussion

We begin our estimations firstly by identifying the slope coefficient heterogeneity and cross-section dependence of the panel. In this regard, we utilized the Pesaran and Yamagata (2008) slope coefficient heterogeneity test, the estimated outcomes provided in Table-2. The said test provides estimated results for both SCH and adjusted SCH. At the same time, the empirical results reveal that both the SCH and adjusted SCH are highly significant at 1% level. Therefore, the Pesaran and Yamagata (2008) SCH test estimates reject the null hypothesis that the slopes are homogenous. Thus, it is concluded that the slopes coefficients of the selected panel are heterogeneous. As mentioned earlier, many factors (including trade, globalization, etc.) increase the dependency of one economy over other economies. However, trade liberalization and globalization play a significant role in attaining various financial, economic, and environmental objectives. However, the dependency on other countries could also lead to facing the spillover effect of an event in one economy. Therefore, it is important to investigate the panel economies' cross-section dependence, especially in an econometric and empirical examination. In this regard, we utilized the Pesaran (2004) CD test, estimates of which is provided in the same Table-2. The estimated results reveal highly significant GDP, ORR, TNR and NGR at 1% and 5% levels. This leads to conclude that economic performance, ORR, TNR and NGR are the variables that have a spillover effect between the BRICS economies. Besides, only the GI is found insignificant in the selected panel. This demonstrates that green innovation in the BRICS economies possesses a spillover effect from one economy to another.

In an empirical investigation, the stationarity of data plays critical role as it leads to the adoption of an efficient estimator for the long-run/short-run analysis. Hence, after analyzing the heterogeneity of slope coefficients and dependence of the cross-section, we further tested for the presence of unit root in the data. In this regard, we utilized the Pesaran (2007) cross-sectionally augmented IPS unit root test and the estimated results are provided in Table-3. The unit root has been analyzed for both the data on level [I (0)] and first difference [I (1)]. Concerning I (0), the estimated results revealed that three variables, i.e., TNR, NGR and GI are ighly statistically significant at 1% and 5% levels.

This indicates that the data under consideration for these three variables are stationary. However, two variables, GDP and ORR namely, are found insignificant, which holds the null hypothesis of the presence of unit root in the data. Besides, these two non-stationary variables have also been tested for the unit root on I (1), which provides significant estimates at 1% level and leads to reject the null hypothesis the unit root presence. Hence, it is concluded that both GDP and ORR are stationary at I (1). Since the data under consideration showed mixed order of integration, thus, it leads to adopting an appropriate econometric approach that handles data at both the leveled stationary and the first difference stationary in one flow.

The mixed order of integration in the data, where the TNR, NGR and GI are stationary at I (0) and GDP and ORR are found stationary at I (1) leads to the adoption of CS-ARDL, which provides both the short-run and long-run coefficient. Also, the said estimator is efficient as it provides reliable estimates by tackling cross-section dependence and weak exogeneity problems (Chudik and Pesaran, 2015; Okumus et al., 2021). The estimated outcomes of CS-ARDL for both short-run and long-run is presented in Table-4. Concerning short-run estimates, it is found that ORR, TNR, NGR and GI has a positive and statistically significant association to the economic performance of BRICS economies. Specifically, a one percent increase in ORR and TNR causes a significant increase in economic performance by 0.053% and 0.058% at 1%, 5% and 10% levels. These results are found consistent to the earlier empirical findings of Hayat and Tahir (2021) and Pérez and Claveria (2020) that natural resources are positively influencing economic growth and performance. These natural resources stimulate economic growth by fulfilling the energy and other resources required in industrial production, which further fuel economic performance in the region. Similarly, if there is one percent increase in the NGR, it will cause a significant increase in economic performance by 0.023% at 1% level. Earlier studies have also identified the positive influence of natural gas on the growth of economy. Such studies include Etokakpan et al. (2020), Topcu et al. (2020), Galadima and Aminu (2020), and Rafindadi and Ozturk (2015), all of which have identified natural gas exhibit promotional influence on economic growth of various countries.

Moreover, environmental related technological innovation (GI) is also reported as positively impacting economic growth of the BRICS economies. Particularly, if the GI is enhanced by one percent, it significantly causes increase in the economic performance of BRICS economies in the selected time period. Environmental-related technological innovation helps promote environmentally friendly machinery, goods, and services, which reduce environmental degradation and contribute to economic growth by enhancing efficient production of goods. Current findings showed consistency to the earlier empirical findings of Zhang and Ma (2021), Bilan et al. (2021), Raza (2020), and Yuan and Zhang (2020). Based on current findings and earlier empirical studies, it is concluded that GI leads to win-win situation from both environmental and economic growth perspective. Concerning the influence of each exogenous variable on the economic performance in short-run, the CS-ARDL also provides error correction equation, which is observed as the speed of adjustment towards the long-run equilibrium point. To be more specific, the ECM showed that the model is converging towards equilibrium at 99% speed of adjustment each year.

As the speed of adjustment ECM showed, with each year's passage, the model is converging towards equilibrium in the long-run. However, the CS-ARDL also provides long-run coefficient estimates for each exogenous variable under consideration. In this regard, the influence of each variable is reported as the same in the long-run as found in the short-run. However, the magnitude of the influence is found relatively higher than the short-run in all the variables. That is, a one percent increase in ORR, TNR, NGR, and GI significantly increase economic growth by 0.064, 0.063, 0.024 and 0.089%, respectively. The obtained results are highly significant at 1%, 5% and 10% levels. Besides, the results also showed consistency to the empirical findings of studies mentioned earlier.

Once the empirical estimates of CS-ARDL are obtained, we further analyzed the long-run coefficients to provide robust and valid outputs. In this regard, we utilized the AMG estimator and the results obtained via this method is provided in Table-5. All the variables showed consistent results to the empirical estimates obtained via CS-ARDL. However, the magnitude of the influence for each variable is found unequal to the earlier estimator. Specifically, a one percent increase in the ORR, TNR, NGR, and GI increase the BRICS economic performance by 0.091, 0.209, 0.015, and 0.046%. The results are found highly statistically significant at 1%, 5%, and 10% levels. Also, the standard errors provided by both the estimators are found very few. The significant and consistent results of both the estimators reveal that the estimated results are robust and reliable. Moreover, concerning similar findings, earlier studies such as Hayat and Tahir (2021), Pérez and Claveria (2020), Etokakpan et al. (2020), Topcu et al. (2020), Galadima and Aminu (2020), Rafindadi and Ozturk (2015), Zhang and Ma (2021), Bilan et al. (2021), Raza (2020), and Yuan and Zhang (2020) have provided similar outcomes of these variables on economic performance for various countries and regions.

After empirically investigating the influence of each exogenous variable on economic performance of the BRICS economies via CS-ARDL and AMG estimators, this study further investigated the causal association that exists between the variables under consideration. In this regard, this study utilized the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneous test, for which the estimated outcomes are provided in Table-6. The estimated results reveal that all the exogenous variables under consideration exhibit a bidirectional causal association to the economic performance in BRICS economies. That is, ORR, TNR, NGR, and GI significantly causes economic growth in the region. However, the feedback affect has been observed that economic growth also significantly causes ORR, TNR, NGR and GI in the study region. The study found highly statistically significant estimates at 1%, 5% and 10% levels, which are enough to reject the null hypothesis of no causal relationship between the variables under consideration. Instead, it is concluded that there is a bidirectional causal association between the variables under study and economic performance in the BRICS economies. Thus, policies targeting ORR, TNR, NGR or GI should also consider economic performance as the empirical estimates suggest that could be critical factors that influence economic performance. Also, policies targeting economic performance of the BRICS economies should also consider these factors, which had a strong influence and association to the economic performance in both the short-run and ling-run. Unlike the study of Rafindadi and Ozturk (2015), the current study provided evidence consistent with the findings of Magazzino et al. (2021), which empirically argued that there is a bidirectional causal association between natural gas rents and economic growth in Japan and Germany.

4.1. Discussion

As per Okumus et al. (2021), Chudik and Pesaran (2015), CS-ARDL is an efficient estimator that allows for cross-section dependence as well as weak exogeneity problem and also deals the mixed order of integration. Therefore, the results of this estimator are critical. Specifically, it is noted that natural resources rents (Including oil rents, natural gas rents, total natural resources rents) are positively affecting economic performance. These results are consistent to the earlier studies that also demonstrates natural resources are promoting economic growth (Hayat and Tahir, 2021; Pérez and Claveria, 2020). Natural resources such as oil and natural gas are the leading energy source in the industrial development and production of a country. However, an increase in these sources would not only fulfil energy demand, but also enhance industrial and economic activities, which enhances aggregate as well as per capital income. Particularly, there are numerous studies available demonstrating natural gas production and consumption significantly promote economic growth and economic performance (Etokakpan et al., 2020; Topcu et al., 2020; Galadima and Aminu, 2020; Rafindadi and Ozturk, 2015). However, massive dependence on natural resources could harm economic growth, as well as environmental quality by producing emissions, climate change, and global warming. In this regard, environmental related technological innovation could be considered as an effective tool of economic as well as environmental recovery. Specifically, the empirical estimate reveals that environmental related technologies promote economic growth as consistent to earlier studies (Zhang and Ma, 2021; Bilan et al., 2020; Raza, 2020; Yuan and Zhang, 2020). Specifically, environmental related technological innovation provides environmentally friendly machinery, goods, and services, which helps tackles environmental issues as well as promote efficient utilization of natural resources. Since, CS-ARDL reveals that the positive relationship of all the explanatory variables exists in both the short-run and long-run. Therefore, the error correction model could provide the speed of adjustment to equilibrium in the long-run. In this case, the error correction is found 99%, revealing that each passing year, the model is approaching to equilibrium with the speed of 99 percent. Hence, these variables could provide critical policy measure for achieving higher economic performance.

5. Conclusion and policy implications

5.1. Conclusion

The world has faced many changes since the last three decades as many events occurred, including the 2003 oil price hike, 2007-08 global financial crisis, Covid-19 pandemic outbreak, and others. However, these events have drastically changed the consumption and production pattern across the globe. Scholars and policy-makers have paid more attention to the natural resource price volatility and economic performance due to the recent pandemic outbreak. In this regard, it is important to investigate both developed and developing economies concerning natural resources price volatility and economic performance in the presence of Covid-19. Therefore, current study analyzed natural resources price volatility and the economic performance of the BRICS economies covering 1990 to 2021. Also, this study considered the role of green technological innovation in economic performance of the said countries. Using various panel data econometric approaches including the Pesaran and Yamagata (2008) SCH test, which demonstrates that the slope coefficients are heterogenous in the panel, the Pesaran (2004) CD test, which confirms the cross-section dependence across the panel, the Pesaran (2007) CIPS unit root test, which provide evidence of the stationarity of data at I (0) for natural gas rents, total natural resources rents, and green technological innovation, while and at I (1) for GDP and oil rents. Concerning the specific influence of explanatory variables on economic performance, the results obtained via CS-ARDL approach demonstrates that oil rents, natural gas rents, total natural resources rents, and green technological innovation are the significant factor of economic performance. An increase of one percent in the said variables would significantly increase the economic performance of the BRICS economies in both the short-run and long-run. Besides, the estimated results of CS-ARDL are also robust check by employing the AMG estimator, which provides robust long-run results and verifies the CS-ARDL estimator's findings. Additionally, the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneous test validates bidirectional causal association between economic performance and explanatory variables, i.e., oil rents, natural gas rents, total natural resources rents, and green technological innovation. This illustrates that any policy targeting any of these variables could significantly affect economic performance of the BRICS economies.

5.2. Policy implications

Based on the empirical findings, this study recommends some practical policy implications which could be advantageous for the policymakers, scholars, and governors regarding economic performance and natural resource price volatility. Firstly, BRICS economies should make a proper check and balance on the natural resources aggregate demand and supply, as well as efficient utilization as it will deduce constant prices of these resources over the time. Specifically, regulating natural resources prices could be critical for natural resources prices volatility while encouraging economic growth and performance. Secondly, to eradicate volatility in the natural resources price, BRICS economies should maintain hedging of the natural resources such as petroleum reserves for about 100-days. This will prevent volatility in the oil prices for a shorter period of time and could be extended even for a longer term. Besides, a proper attention to economic activities must be paid because economic activities significantly affect demand and supply of natural resources, which affect prices of these resources. Thus, natural resources hedging could be used as a tool of recovery for natural resources volatility and promoting economic performance. Thirdly, price ceiling or freezing policy could be effective for not only reduce natural resources volatility, but also helps maintain economic growth sustainability as it helps stabilize economic activities. Lastly, green technological innovation should be promoted as it substantially leads to win-win situation regarding environmental degradation control (as per literature) and economic growth achievement. That is, green technologies will promote investment and production while efficiently utilizing natural resources, which could strongly promote economic performance of the region. This policy will help maintain about the same demand for natural resources, which would counter fluctuations in natural resources. Besides, these variables are strongly connected to economic performance. That is, a policy change in any of the explanatory variable should affect economic performance. Therefore, policymakers should consider economic performance while tackling natural resources volatility or increasing green technological innovation.

5.3. Limitations of the study

Although, this study has some innovative findings. Still, this research is limited in few dimensions. Specifically, this study included the Covid-19 period data, but exemplify the connection of natural resources price volatility and economic performance. Therefore, future researchers should pay attention to this nexus particularly in the Covid-19 pandemic. Secondly, this study is limited only to BRICS economies. However, this panel could be extended, which must consider developed as well as developing economies. Thirdly, this study used only three variables to indicate natural resources prices. However, this set could be extended by including other natural and mineral resources such as gold, platinum, silver, forests, etc. To provide extensive results and policy measures.

CRediT authorship contribution statement

Jun Wen: Supervision, Project administration, Funding acquisition. **Nafeesa Mughal:** Formal analysis, Conceptualization. **Maryam Kashif:** Conceptualization, Data curation, Methodology, Software, Formal analysis. **Vipin Jain:** Writing – original draft, Data curation. **Phan The Cong:** Writing – original draft, Data curation, Methodology, Software.

Data availability

The data that has been used is confidential.

References

Adedoyin, F.F., Gumede, M.I., Bekun, F.V., Etokakpan, M.U., Balsalobre-Lorente, D., 2020. Modelling coal rent, economic growth and CO2 emissions: does regulatory quality matter in BRICS economies? Sci. Total Environ. 710, 136284. https://doi.org/10.1016/j.scitotenv.2019.136284.

Aguirre, M., Ibikunle, G., 2014. Determinants of renewable energy growth: a global sample analysis. Energy Pol. 69, 374–384. https://doi.org/10.1016/j.enpol.2014.02.036.

Akinsola, M.O., Odhiambo, N.M., 2020. Asymmetric effect of oil price on economic growth: panel analysis of low-income oil-importing countries. Energy Rep. 6, 1057–1066. https://doi.org/10.1016/j.egyr.2020.04.023.
Atil, A., Nawaz, K., Lahiani, A., Roubaud, D., 2020. Are natural resources a blessing or a curse for financial development in Pakistan? The importance of oil prices, economic growth and economic globalization. Resour. Pol. 67, 101683. https://doi.org/10.1016/j.resourpol.2020.101683.
Baba, S., 2020. A vector autoregressive analysis of oil price volatility and economic growth in Nigeria (1997-2017). J. Int. Bus. Innovat. Strat. Manag. 4, 29–46. http://www.jibism.org/core_files/index.php/JIBISM/article/view/119.
Balsalobre-Lorente, D., Álvarez-Herranz, A., Shahbaz, M., 2019. The long-term effect of economic growth, energy innovation, energy use on environmental quality. In: Energy and Environmental Strategies in the Era of Globalization. Springer, Cham, pp. 1–34.
Balsalobre-Lorente, D., Leitão, N.C., Bekun, F.V., 2021a. Fresh validation of the low carbon development hypothesis under the EKC scheme in Portugal, Italy, Greece and Spain. Energ. 14, 250. https://doi.org/10.3390/en14010250.
Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., Farhani, S., 2018. How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Pol. 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050.
Balsalobre-Lorente, D., Sinha, A., Driha, O.M., Mubarik, M.S., 2021b. Assessing the impacts of ageing and natural resource extraction on carbon emissions: a proposed policy framework for European economies. J. Clean. Prod. 296, 126470. https://doi.org/10.1016/j.jclepro.2021.126470.
Banday, U.J., Aneja, R., 2020. Renewable and non-renewable energy consumption, economic growth and carbon emission in BRICS: evidence from bootstrap panel causality. Int. J. Energy Sect. Manag. 14, 248–260. https://doi.org/10.1108/IJESM-02-2019-0007.
Bilan, Y., Hussain, H.I., Haseeb, M., Kot, S., 2020. Sustainability and economic performance: role of organizational learning and innovation. Eng. Econ. 31, 93–103. https://doi.org/10.5755/j01.ee.31.1.24045.
Bilgili, F., Lorente, D.B., Kuşkaya, S., Ünlü, F., Gençoğlu, P., Rosha, P., 2021. The role of hydropower energy in the level of CO2 emissions: an application of continuous wavelet transform. Renew. Energy 178, 283–294. https://doi.org/10.1016/j.renene.2021.06.015.
Caglar, A.E., Balsalobre-Lorente, D., Akin, C.S., 2021. Analysing the ecological footprint in EU-5 countries under a scenario of carbon neutrality: evidence from newly developed sharp and smooth structural breaks in unit root testing. J. Environ. Manag. 295, 113155. https://doi.org/10.1016/j.jenvman.2021.113155.
Campello, M., Galvao, A.F., Juhl, T., 2019. Testing for slope heterogeneity bias in panel data models. J. Bus. Econ. Stat. 37, 749–760. https://doi.org/10.1080/07350015.2017.1421545.
Cao, Y., Wan, N., Zhang, H., Zhang, X., Zhou, Q., 2020. Linking environmental regulation and economic growth through technological innovation and resource consumption: analysis of spatial interaction patterns of urban agglomerations. Ecol. Indicat. 112, 106062. https://doi.org/10.1016/j.ecolind.2019.106062.
Chien, F., Chau, K.A.Y., Jalees, T., Zhang, Y., Nguyen, V.A.N.C., Baloch, Z.A., 2021. Crude oil price volatility and economic growth: mediating role of macroeconomic indicators. Singap. Econ. Rev. 1–25. https://doi.org/10.1142/S021759082150051X.
Chudik, A., Mohaddes, K., Pesaran, M.H., Raissi, M., 2017. Is there a debt-threshold effect on output growth? Rev. Econ. Stat. 99, 135–150. https://doi.org/10.1162/REST_a_00593.
Chudik, A., Pesaran, M.H., 2013. Large Panel Data Models with Cross-Sectional Dependence: A Survey. SSRN Electron. https://doi.org/10.2139/ssrn.2316333.
Chudik, A., Pesaran, M.H., 2015. Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. J. Econom. 188, 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007.
Dhaene, G., Jochmans, K., 2015. Split-panel jackknife estimation of fixed-effect models. Rev. Econ. Stud. 82, 991–1030. https://doi.org/10.1093/restud/rdv007.
Dumitrescu, E.-I., Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. Econ. Modell. 29, 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014.
Eberhardt, M., Bond, S., 2009. Cross-section Dependence in Nonstationary Panel Models: a Novel Estimator. MPRA Paper 17692. University Library of Munich.
Eberhardt, M., Teal, F., 2010. Productivity analysis in global manufacturing production. https://ora.ox.ac.uk/objects/uuid:ea831625-9014-40ec-abc5-516ecfbd2118/download_file?file_format=pdf&safe_filename=paper515.pdf&type_of_work=Working+paper.
Epo, B.N., Faha, D.R.N., 2020. Natural resources, institutional quality, and economic growth: an African tale. Eur. J. Dev. Res. 32, 99–128. https://doi.org/10.1057/s41287-019-00222-6.
Etokakpan, M.U., Solarin, S.A., Yorucu, V., Bekun, F.V., Sarkodie, S.A., 2020. Modeling natural gas consumption, capital formation, globalization, CO2 emissions and economic growth nexus in Malaysia: fresh evidence from combined cointegration and causality analysis. Energy. Strat. Rev. 31, 100526. https://doi.org/10.1016/j.esr.2020.100526.
Galadima, M.D., Aminu, A.W., 2020. Nonlinear unit root and nonlinear causality in natural gas - economic growth nexus: evidence from Nigeria. Energy 190, 116415. https://doi.org/10.1016/j.energy.2019.116415.
Gelb, A.H., 1988. Oil Windfalls: Blessing or Curse? Oxford university press, New York.
Gkillas, K., Gupta, R., Pierdzioch, C., 2020. Forecasting realized oil-price volatility: the role of financial stress and asymmetric loss. J. Int. Money Finance 104, 102137. https://doi.org/10.1016/j.jimonfin.2020.102137.
Gong, X., Wang, M., Shao, L., 2020. The impact of macro economy on the oil price volatility from the perspective of mixing frequency. Int. J. Finance Econ. https://doi.org/10.1002/ijfe.2383.
Guan, L., Zhang, W.-W., Ahmad, F., Naqvi, B., 2021. The volatility of natural resource prices and its impact on the economic growth for natural resource-dependent economies: a comparison of oil and gold dependent economies. Resour. Pol. 72, 102125. https://doi.org/10.1016/j.resourpol.2021.102125.
Gylfason, T., Zoega, G., 2006. Natural resources and economic growth: the role of investment. World Econ. 29, 1091–1115. https://doi.org/10.1111/j.1467-9701.2006.00807.x.
Hayat, A., Tahir, M., 2021. Natural resources volatility and economic growth: evidence from the resource-rich region. J. Risk Financ. Manag. 14, 84. https://doi.org/10.3390/jrfm14020084.
Hoxtell, W., Goldthau, A., 2012. Addressing Carbon Emissions and Oil Price Volatility. Challenges and Opportunities for Trans-Atlantic Energy Cooperation. Global Public Policy Institute, Berlin, Germany.
Joya, O., 2015. Growth and volatility in resource-rich countries: does diversification help? Struct. Change Econ. Dynam. 35, 38–55. https://doi.org/10.1016/j.strueco.2015.10.001.
Khan, Z., Hussain, M., Shahbaz, M., Yang, S., Jiao, Z., 2020. Natural resource abundance, technological innovation, and human capital nexus with financial development: a case study of China. Resour. Pol. 65, 101585.
Leitão, N.C., Lorente, D.B., 2020. The linkage between economic growth, renewable energy, tourism, CO2 emissions, and international trade: the evidence for the European Union. Energ. 13, 4838. https://doi.org/10.3390/en13184838.
Leong, W., Mohaddes, K., 2011. Institutions and the Volatility Curse. SSRN Electron. https://doi.org/10.2139/ssrn.1885569.
Lin, Y., Xiao, Y., Li, F., 2020. Forecasting crude oil price volatility via a HM-EGARCH model. Energy Econ. 87, 104693. https://doi.org/10.1016/j.eneco.2020.104693.
Ma, Q., Zhang, M., Ali, S., Kirikkaleli, D., Khan, Z., 2021. Natural resources commodity prices volatility and economic performance: evidence from China pre and post COVID-19. Resour. Pol. 74, 102338. https://doi.org/10.1016/j.resourpol.2021.102338.
Magazzino, C., Mele, M., Schneider, N., 2021. A D2C algorithm on the natural gas consumption and economic growth: challenges faced by Germany and Japan. Energy 219, 119586. https://doi.org/10.1016/j.energy.2020.119586.
Maheu, J.M., Song, Y., Yang, Q., 2020. Oil price shocks and economic growth: the volatility link. Int. J. Forecast. 36, 570–587. https://doi.org/10.1016/j.ijforecast.2019.07.008.
Mohamued, E.A., Ahmed, M., Pypłacz, P., Liczmańska-Kopcewicz, K., Khan, M.A., 2021. Global oil price and innovation for sustainability: the impact of R&D spending, oil price and oil price volatility on GHG emissions. Energ. 14, 1757. https://doi.org/10.3390/en14061757.
Nonejad, N., 2020. Crude oil price volatility and short-term predictability of the real U.S. GDP growth rate. Econ. Lett. 186, 108527. https://doi.org/10.1016/j.econlet.2019.108527.
Okumus, I., Guzel, A.E., Destek, M.A., 2021. Renewable, non-renewable energy consumption and economic growth nexus in G7: fresh evidence from CS-ARDL. Environ. Sci. Pollut. Res. Int. https://doi.org/10.1007/s11356-021-14618-7.
Paramati, S.R., Roca, E., 2019. Does tourism drive house prices in the OECD economies? Evidence from augmented mean group estimator. Tourism Manag. 74, 392–395. https://doi.org/10.1016/j.tourman.2019.04.023.
Pérez, C., Claveria, O., 2020. Natural resources and human development: evidence from mineral-dependent African countries using exploratory graphical analysis. Resour. Pol. 65, 101535. https://doi.org/10.1016/j.resourpol.2019.101535.
Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econom. 142, 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010Get.
Pesaran, M.H., 2004. General diagnostic tests for cross-sectional dependence in panels. Empir. Econ. 60, 13–50. https://doi.org/10.1007/s00181-020-01875-7.
Pesaran, M.H., 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica 74, 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econ. 22, 265–312. https://doi.org/10.1002/jae.951.
Rafindadi, A.A., Ozturk, I., 2015. Natural gas consumption and economic growth nexus: is the 10th Malaysian plan attainable within the limits of its resource? Renew. Sustain. Energy Rev. 49, 1221–1232. https://doi.org/10.1016/j.rser.2015.05.007.
Rahim, S., Murshed, M., Umarbeyli, S., Kirikkaleli, D., Ahmad, M., Tufail, M., Wahab, S., 2021. Do natural resources abundance and human capital development promote economic growth? A study on the resource curse hypothesis in Next Eleven countries. Resour. Environ. Sustain 4, 100018. https://doi.org/10.1016/j.resenv.2021.100018.
Raza, Z., 2020. Effects of regulation-driven green innovations on short sea shippinǵs environmental and economic performance. Transp. Res. D Transp. Environ. 84, 102340. https://doi.org/10.1016/j.trd.2020.102340.
Sachs, J.D., Warner, A.M., 2001. The curse of natural resources. Eur. Econ. Rev. 45, 827–838. https://doi.org/10.1016/S0014-2921(01)00125-8.
Sadorsky, P., 2014. The effect of urbanization on CO2 emissions in emerging economies. Energy Econ. 41, 147–153. https://doi.org/10.1016/j.eneco.2013.11.007.
Sun, L., Wang, Y., 2021. Global economic performance and natural resources commodity prices volatility: evidence from pre and post COVID-19 era. Resour. Pol. 74, 102393. https://doi.org/10.1016/j.resourpol.2021.102393.
Topcu, E., Altinoz, B., Aslan, A., 2020. Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation. Resour. Pol. 66, 101622. https://doi.org/10.1016/j.resourpol.2020.101622.
Yuan, B., Zhang, Y., 2020. Flexible environmental policy, technological innovation and sustainable development of China's industry: the moderating effect of environment regulatory enforcement. J. Clean. Prod. 243, 118543. https://doi.org/10.1016/j.jclepro.2019.118543.

Zeraibi, A., Balsalobre-Lorente, D., Murshed, M., 2021. The influences of renewable electricity generation, technological innovation, financial development, and economic growth on ecological footprints in ASEAN-5 countries. Environ. Sci. Pollut. Res. Int. 28, 51003–51021. https://doi.org/10.1007/s11356-021-14301-x.

Zeraibi, A., Balsalobre-Lorente, D., Shehzad, K., 2020. Examining the asymmetric nexus between energy consumption, technological innovation, and economic growth; Does energy consumption and technology boost economic development? Sustainability 12, 8867. https://doi.org/10.3390/su12218867.

Zhang, Q., Ma, Y., 2021. The impact of environmental management on firm economic performance: the mediating effect of green innovation and the moderating effect of environmental leadership. J. Clean. Prod. 292, 126057. https://doi.org/10.1016/j.jclepro.2021.126057.

Zhou, B., Zeng, X., Jiang, L., Xue, B., 2020a. High-quality economic growth under the influence of technological innovation preference in China: a numerical simulation from the government financial perspective. Struct. Change Econ. Dynam. 54, 163–172. https://doi.org/10.1016/j.strueco.2020.04.010.

Zhou, X., Song, M., Cui, L., 2020b. Driving force for China's economic development under Industry 4.0 and circular economy: technological innovation or structural change? J. Clean. Prod. 271, 122680. https://doi.org/10.1016/j.jclepro.2020.122680.