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Sustainable economic growth via human capital and cleaner energy: evidence from non-parametric panel methods

Boya Sun[a], Wenzhong Zhu[b], Nafeesa Mughal[a], Tolassa Temesgen Hordofa[a], Rinat Zhanbayev[c]* and Iskandar Muda[d]

[a]School of Economics and Finance, Xi'an Jiaotong University, Xi'an, Shaanxi, China; [b]School of Business, Guangdong University of Foreign Studies, Guangzhou, China; [c]Science Department, National Engineering Academy of the Republic of Kazakhstan, Almaty, Kazakhstan; [d]Faculty Economic and Business, Jl. Prof TM Hanafiah 12 Campus, Universitas Sumatera Utara, Padang Bulan, Medan, Indonesia

ABSTRACT

The association between resource rents and economic growth is one of the key issues that have attracted the attention of both policy-makers and scholars. Several attempts have been made regarding the association, yet the literature holds the gap. The present research intends to explore the connection between natural resource volatility and economic performance in seven (G-7) countries. For the time frame from 1990 to 2020, this study also examines the role of technological innovation (TI), human capital (HCI), and research and development budget for renewable energy (RER&D). Empirical results asserted that the variables under study are cointegrated. Employing a novel non-parametric panel quantile method of moments regression and quantile-on-quantile, the outcomes propose that natural resources volatility significantly affects EP throughout the quantiles. This negative impact is valid for the aggregate panel of countries and cross-sections. Natural resource volatility supports the resource curse hypothesis for G7 economies. On the other hand, HCI and TI are significant economic performance factors. From lower to higher quantiles, the magnitude and significance levels increase. The variable for cleaner energy investment is also positively related to economic performance yet insignificant in the higher quantile. The study recommends channeling natural resource rents to effectively and fully transfer the full potential of natural resources to other real sectors of the economy to fully utilize the benefit from it.

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CONTACT Wenzhong Zhu wenzhong8988@sina.com
*Old affiliation: Department of Finance and Banking Sciences, The Almaty University of Power Engineering and Telecommunications, Almaty, Kazakhstan.

1. Introduction

Natural resource (NR) preservation and conservation are crucial for human survival. The world is experiencing continual change and uncertainty, particularly in socioeconomic and geopolitical situations (Sinha & Sengupta, 2019). Continuous NR extraction and exploration will negatively impact the availability of NR. Likewise, NR renders the present environment and ecosystems unpleasant and dangerous since using NR encourages pollution emissions. However, neglecting the use of NR could harm the EP and the growth of a country. As a result, preserving biological diversity on earth has been a discussion topic among governments and scholars for several decades. Developing and developed nations found it hard to balance NR consumption and growth (Hassan et al., 2019). The prevailing literature offers mixed findings concerning the nexus between development (economic growth) and NR, which could be specifically divided into groups: firstly, even with the abundance of NR, it is found to have an inverse link with both economic growth and financial development known as the curse of NR.[1] Secondly, a group of scholars provides empirical results regarding NR positive and contributing role to economic growth.[2] The NR curse is still a debated phenomenon which motivates the present study to delve into greater depth and understanding, revealing other dynamics and explanations.

Recently, NR volatility (NRV) has engrossed academic attention (Lobato et al., 2021; Q. Ma et al., 2021). Volatility, in simple words, refers to the degree of variation or inconsistency of a statistical value of NR rents across a period. The volatility (fluctuations) of NR prices is also an essential indication of industrial output and economic activity; it impacts the economic progress of a nation. According to the basic idea of demand and supply, an increase in the price of NR might decrease their demand. According to Bansal and Kumar (2021) and Kilian (2008), a rise in NR in oil-exporting nations causes a rise in stock prices and share values due to oil export earnings. Nonetheless, this may also have a negative impact on participation in the stock market in the oil-importing nations, although the results are inconsistent and conflicting (Silvapulle et al., 2017; Umar, Ji, Mirza, & Naqvi, 2021). In addition to other NR, oil prices influence the market and the country's economic performance (EP). Particularly, a decline in oil prices reduces the cost of production, boosting economic development in the region (Hmaittane et al., 2019; Song et al., 2020). Consequently, stock prices rise owing to increasing anticipated future revenue and profitability (Umar, Ji, Mirza, & Rahat, 2021). In contrast, a rise in oil prices decreased its demand, resulting in a drop in industrial output owing to high manufacturing costs. Additionally, this generates a decline in shareholders' predicted future revenue and profits, which delays investment and creates an uncertain economic environment (Gao et al., 2021). Nonetheless, the literature on oil price volatility offers evidence of the influence of oil prices and oil price volatility on various financial and economic factors. Still, the relationship between the volatility of NR and EP, which has become a pressing concern in recent years, is little documented. Consequently, this study complements the current literature and draws academic attention to this enduring topic.

The recent global economic and financial uncertainties highlight the importance of NR volatility and its effects on the EP concept, which might be critical to micro and macroeconomic growth: company income, household spending, and the national

economy. Energy, along with labor and capital, is a vital production element in all emerging and developed nations. Furthermore, energy consumption is a primary factor influencing growth and development. A rise in NR commodity prices, particularly petroleum costs, might affect production. These gas and oil price shocks initially reduce cumulative demand because increased oil and gas prices cause income redistribution across net oil-importing and exporting nations. Rising oil and gas costs could impair labor and capital productivity owing to the firm's assigned budget limits. As a result of rising oil and gas costs, people use less energy. Furthermore, this low level of energy usage anticipates a rise in the unemployment rate due to a decline in real wage. As a result, a decline in real wages adds to poverty and unemployment and lowers the country's EP. Therefore, it is pertinent to investigate the association between the two since a substantial drop has been seen in the EP. In contrast, there has been an increase in NRV.

The primary research objective is to analyze the connection between NRV and EP. The available literature is more extensive concerning the connotation of NR and economic growth, yet scant on NRV and EP. In this regard, it is imperative to examine the true connection between these variables, particularly in the developed nations, as these economies play a vital role in global policies regarding economic growth and NR. The second aim of this research is to examine the association between human capital (HCI) and EP. However, many studies in the literature provide empirical evidence regarding the said relationship. Unlike these studies that consider education, health, or both, this study used a comprehensive index indicating HCI. Lastly, this research explores the impact of technological innovation (TI) and research and development (R&D) for renewable energy on EP. Nevertheless, most of the prevailing literature covered the role of TI and renewable energy R&D from the environmental perspective, either in the carbon emissions or the greenhouse gas emissions. Yet, the gap is still prevalent in terms of its role in the EP in case of the developed nations; therefore, the present research tends to cover this gap via advanced empirical tools.

The contribution of this study is multi-dimensional. For instance, one of the pioneering studies empirically analyzes the influence of NRV on EP combinedly and separately for each G-7 country. The newly estimated results via extended time could help authorities and policymakers to take appropriate steps to attain sustained EP. In addition to the contribution of the study to the existing literature, this study also identified the true influence of the HCI index on the EP of developed economies, which is a more thorough metric than the one used in the prior literature. Furthermore, there is relatively little-to-no evidence regarding the impact of renewable energy R&D and TI on the EP, particularly in the case of the G-7 economies. Therefore, this study provides novel empirical estimates, which scholars could extend for various developed, emerging, and under-developed economies. To resolve the problems as discussed earlier, this study employed various panel data estimation strategies along with the novel method of moment quantile regression (MMQR) and quantile-on-quantile (QQ) regression to comprehensively analyze volatility in the variables, as well as the influence of NRV and control variables on the EP of the G-7 economies. Despite various econometric approaches, this study focused on the MMQR and QQ regression due to its effectiveness in dealing with the non-linearity

or asymmetry issue. Besides, these approaches are those of the few metrics that thoroughly examine the nexus between the eat scale, location, and quantile variables, making these estimators more robust than the traditional regressors, which only report the mean or average results. Such empirical techniques will help establish relevant and appropriate policies to attain regional sustainable development.

2. Literature review

2.1. Literature review for relevant variables

Concerning NR and its association with various economic, financial, and non-economic indicators, the extensive literature comprehensively covers the association of all the relevant variables.

For the last three decades, scholarly arguments regarding NR and growth nexus have gotten considerable attention from policy-makers and scholars. Most of the literature discloses that NR plays an extensive part in growth. Specifically, the literature can be categorized into three classes, where the first category supports the stance of the resource curse in a country or region. In this sense, Auty (2002) and Sachs and Warner (1995) reveal that NR abundance causes the lagging of economic development relative to economies with fewer NR—validating the NR curse hypothesis. The recent studies also evident NR abundance as the leading factor of lagging economic and financial development (Asif et al., 2020; Caselli & Cunningham, 2009; Guan et al., 2020; Khan, Ali, Jinyu, et al., 2020; Khan et al., 2022). The second category consists of those empirical studies that consider resources as blessings. Specifically, the study by Dogan et al. (2020), Hayat and Tahir (2021) and Hussain et al. (2020) provide evidence for emerging, developed, and resource-rich regions by claiming that NR provides an additional income that helps support the industrial as well as enhance investments in other economic sectors and financial sectors (Ferrat et al., 2022). Due to such income and investment enhancement properties, these studies argued that NR is a blessing from a development perspective. The last category reveals that there are other factors, the development of which helps transform the NR curse into NR blessings. For instance, several studies validate the resource curse hypothesis in different regions (Brunschweiler, 2007; Caselli & Cunningham, 2009; Rahim et al., 2021; Sala-i-Martin & Subramanian, 2013; Tu et al., 2019). Still, these studies claimed that developed HCI improved institutional quality, enhanced globalization, and the leaders' behavior could significantly reduce its negative effect and helps in promoting the positive impact of NR on economic performance and growth.

Nonetheless, the discussion on the impact of NR on economic growth has already filled a great part of the literature. In recent times, NRV emerged as a hot topic and a crucial issue among policy-makers. For instance, Hayat and Tahir (2021) analyzed the resource-rich region from 1970–2016 and concluded that NR is a driver of economic growth. Still, NRV plays a destructive role in the region's economic development. Since the record industrial sectors are heavily dependent on energy consumption. Therefore, higher economic growth is among the leading factors that enhance energy consumption, while energy prices reduce energy consumption (Murad et al., 2019). In addition to NRV, Benramdane (2017) uses the vector

autoregressive (VAR) technique to reveal that the negative growth impact of oil price volatility reduces the oil boom's positive influence in Algeria during 1970–2012. Hence, the author argued that oil price volatility pushes the resource curse paradox besides resource abundance. Similar results are also provided by the recent study of Umar, Ji, Mirza, and Naqvi (2021), which validates the decline of banking efficiency when the prices of NR increase. Similarly, Q. Ma et al. (2021) and Sun and Wang (2021) examined the global economy and China in the pre and post-COVID-19 pandemic spans. Utilizing the wavelet approach, these studies demonstrate that the main reason for the volatility in NR commodity prices is the COVID-19 outbreak. Besides, the earlier study found a bidirectional causal link among the variables, while the latter claimed no causal association (Zhanbayev et al., 2020; Zhanbayev & Irfan, 2022). In contrast, Wen et al. (2022) investigated BRICS countries during 1990–2021 by applying the CS-ARDL and AMG approaches to conclude that NRV is beneficial for the better EP of the country. However, there is an increasing debate on NRV and its economic impact. Still, the contradictory evidence provides a blurred image regarding the true impact of NR that leads to the construction of detrimental policies and complicates the area for scholars and future researchers.

Although NR could have a substantial relationship with the EP, these NRs are the key factors of fossil fuel, which could adversely affect the environment via carbon emissions. However, the existing strand of the literature recommends several measures to control negative environmental hazards. Such measures include green loans (Umar, Ji, Mirza, & Rahat, 2021), exports and eco-innovation (Khan, Ali, Kirikkaleli, et al., 2020; Khan, Hussain, Shahbaz, et al., 2020), green funds (Ielasi et al., 2018; Ji, Chen, et al., 2021; Naqvi et al., 2021), fiscal decentralization (Khan, Ali, et al., 2021), environmentally-friendly investment (Ji, Zhang, et al., 2021), TI (Khan, Ali, Umar, et al., 2020), financial inclusion (Qin et al., 2021), environmental regulations (Khan et al., 2019), financial development (2021 b), environmental policies (Shahzad et al., 2021), reduced composite risk (Dorfleitner & Grebler, 2022; Khan, Murshed, et al., 2021), investment in the new energy industry (Luan et al., 2022), environmental research and development (Jiang et al., 2022), HCI (Khan, Malik, Latif, et al., 2020), renewable energy (Cai et al., 2022), among others. Still, most studies recommend the sustainable use of NR for environmental and economic stability (Hordofa et al., 2022; Ibrahim et al., 2021; Jun et al., 2022; Ma et al., 2022; Mughal et al., 2021, 2022, 0; Nawaz et al., 2015, 2018; Temesgen Hordofa et al., 2023; The Phan et al., 2021; Wen et al., 2021; Wen et al., 2022; Yating et al., 2022).

The importance of HCI in economic growth cannot be ignored since it significantly contributes to almost all sectors of the economy. The present literature offers broad evidence about the influence of HCI on growth. Khan et al. (2019) examined developing economies from 1996–2018. The empirical results asserted that HCI's life expectancy and education expenditures significantly promote economic growth. In the case of 21 developing nations Yang (2020) investigated the correlation between health expenditures and growth at various stages of HCI. The results demonstrate a negative correlation between economic growth and health expenditure at the lower HCI while positive at the higher level of HCI. On the other hand, increased HCI enhances environmental degradation (Sarkodie et al., 2020). Specifically, the higher

level of HCI promotes fossil fuel energy, positively affecting foreign direct investment and the environment and leading to higher economic growth (Azam et al., 2019). Higher economic growth further increases the human development index in the shape of higher income levels, literacy rates, and life expectancy in the Sub-Saharan economies (Alola et al., 2021). Alola et al. (2021) and Dasci Sonmez and Cemaloglu (2021) analyzed 31 developed and developing economies from 1999 to 2015. The estimated findings revealed that the HCI components, such as health, education, and technology or innovation, significantly promote economic growth in selected economies. Fukao et al. (2021) considered the extended data in the case of Japan from 1885 to 2015. The study reveals that labor productivity, improvement in labor quality, and the total factor productivity of laborers have significantly risen 46-fold, 35%, and 36%, respectively. This substantial improvement in HCI significantly contributes to the economic growth of the country. Concerning causality analysis between both, Abdouli and Omri (2021) revealed a bidirectional causal association between economic growth and HCI while HCI is an important aspect of economic growth in various countries and regions. However, it also promotes environmental sustainability by reducing environmental hazards (Lin et al., 2021).

TI and research and development play a substantial part in reaching higher economic growth and sustainable development in a country or region. Many scholars have explored the nexus of TI on economic growth and environmental quality in the existing literature. A recent study by Kihombo et al. (2021) investigated West Asian and Middle East economies from 1990–2017. The empirical findings asserted that TI substantially encourages economic growth and environmental sustainability. However, financial development is the major factor in increasing energy innovation, which causes higher economic growth, minimizes emissions, and promotes environmental quality (Baloch et al., 2021). Similarly, Broughel and Thierer (2019) reviewed the existing literature concerning the influence of TI on growth, living standards, and human well-being. The study concludes that most of the literature conveys the affirmative effect of innovation on economic growth and quality of life. The earlier study of Guloglu and Tekin (2012) empirically analyzed higher-income OECD economies by employing tri-variate panel VAR, GMM, and panel fixed effects methods. Empirical results demonstrate that research and development cause TI and that Granger causes regional economic growth. The earlier study by Aghion and Howitt (1996) argued that the level of research tends to co-vary with the growth rate positively that underlies long-run economic growth due to secondary innovations caused by the development process. Silaghi et al. (2014) examined 10 CEE countries from 1998 and 2008. The study focused on differentiating public and private business research and development. It revealed that business research and development significantly enhance growth, while public research and development exhibit insignificant growth influences. Nonetheless, the contribution of research and development is substantial to economic growth. Yet, it has an influential role in sustaining environmental quality. The recent studies of Wang and Wang (2019), Wang and Zhang (2020), and Zafar et al. (2019) empirically demonstrate that renewable energy-related research and development help endorse efficient technology and renewable adoption that increases economic growth as well as promotes a sustainable environment.

2.2. Literature summary and research gap

It is well known that economic growth and EP are connected to NR, where the debate about the effect of NR on growth is prevailing. Yet, various non-natural and natural shocks occurred in the last few decades, which led to cause inconsistency in NR (known as NRV) contribution to EP and growth. However, the literature covers the link between NR and growth (Auty, 2002; Caselli & Cunningham, 2009; Rahim et al., 2021). Still, the literature is scant regarding the true impact of NRV on EP, particularly in developed economies, such as the G-7 economies. Therefore, it is essential to analyze the situation for appropriate policy suggestions, as the hardly available literature suggests its adverse impact on EP. In addition, existing studies cover various economic and non-economic factors of growth, such as HCI, TI, and R&D, to economic growth. Still, these studies provide insufficient and contradictory findings, which motivate this study to consider these variables in connection to the EP of the developed nations.

3. Methodology

3.1. Theoretical framework and model specification

Concerning the true association between NRV and EP, it is observed that volatility in NR prices causes vagueness in the NR market, which substantially leads the investors to restrict and postpone their investment due to ambiguous circumstances for future outcomes (Berger, 2022). Due to this decreased investment, the industrial sector reduces its production and manufacturing processes. Such reduced investment reduces EP or industrial activities of the industrial sector and economic growth. Hence, NRV could adversely impact EP, given as: $\delta_1 = \frac{\partial EP}{\partial NRV_{it}} < 0$. On the other hand, the given literature asserted that HCI, education, skill, awareness, TI, and renewable energy R&D significantly enhance EP by increasing economic activities and speeding up the production of goods and services via improved technology. However, renewable energy R&D precedes the adaptation of green energy resources, energy efficiency equipment, and lower energy-intensive products, reducing environmental degradation and causing higher economic growth. Hence, the renewable energy R&D, improved HCI, and TI significantly enhances EP given as: $\delta_2 = \frac{\partial EP}{\partial HCI_{it}} > 0$, $\delta_3 = \frac{\partial EP}{\partial TI_{it}} > 0$, and $\delta_4 = \frac{\partial EP}{\partial RERD_{it}} > 0$, respectively. Following Wen et al. (2021), this study built the model consisting of the priorly mentioned variables:

3.1.1 Model

$$EP_{it} = f(NRV_{it}, HCI_{it}, TI_{it}, RER\&D_{it})$$

The model demonstrates that EP is the function of NRV, HCI, TI, and research and development. The above-mentioned general model transformed into the following regression model as motivated by the study of Khan et al. (2020):

$$EP_{it} = \alpha_1 + \delta_1 NRV_{it} + \delta_2 HCI_{it} + \delta_3 TI_{it} + \delta_4 RER\&D_{it} + \varepsilon_{it} \quad (1)$$

From Equation (1), α is the intercept and $\delta's$ are the coefficients to estimate, while the right-hand side of the equation provides all the explanatory variables. In addition, the cross-section and time-series are indicated via i and t in subscripts. Besides, ε_{it} is the random error term of the regression model.

In the above model, a total of five variables have been used. That is, EP is captured by gross domestic product (GDP). It is well-known that GDP is an extensive measure of EP as it accounts for the aggregate production, consumption, investment, and government expenditure, indicating the health of an economy (Khan et al., 2019). Consequently, the GDP could better replicate the country's EP or region. In contrast, the current study uses NRV as the main explanatory variable—captured by total NR rents. Since the NR rents act as additional income to the treasure of the economy, which follows inconsistent contribution due to various global and domestic events, NR rents could be used as a proxy for NR volatility. In addition, this study uses the HCI index (HCI) to analyze its influence on EP. A recent study by Dasci Sonmez and Cemaloglu, 2021 suggests that using a human capital index is an appropriate proxy rather than narrowing this concept to education, health expenditures, etc. Moreover, TI and renewable energy research and development (RER&D) are used as controlled variables to extensively analyze the economic factors and determinants of EP extensively. Data for all the mentioned variables are extracted from various sources, covering the period from 1990 to 2020. This period covers 31 years of data obtained for a group of seven (G-7) countries: Italy, France, Germany, the United Kingdom, Canada, Japan, and the United States. Nonetheless, several studies have attempted to explore the nexus between NR volatility and economic growth by utilizing the limited time period and conventional measures (regressors). However, to provide timely and realistic estimates, this study uses the extended time period for the available dataset, particularly in the G-7 economies. The major reason for selecting the G-7 economies for empirical examination is that these economies play a significant role in the alteration and adaptation of global policies. Thus, the present empirical estimates could be generalized to other developed and developing nations.

The specification of variables and sources for data extraction are provided in Table 1.

3.2. Estimation strategy

The present research adopted various panel data methods to empirically test the link between NRV and EP in the G-7 economies. Such methods include normality tests, slope coefficient heterogeneity (SCH), cross-section dependence (CD), and cointegration tests. Since the normality test reveals that each study variable holds an abnormal property distribution, we employed the novel method of moments panel quantile regression (MMQR).

3.2.1. Normality detection and descriptive stats

Before the empirical examination of the study variables, the present study provides descriptive statics for each variable. Descriptive statistics holds in an econometric analysis as it provides the data in a summarized form. In this sense, the descriptive stats

Table 1. Variables measurement and sources.

Variable	Specifications	Data extraction source
EP	The improvement or rise in the monetary value of products and services produced in the country over time is adjusted for inflation and commonly measured as GDP in constant 2010US$.	https://databank.world-bank.org/source/world-development-indicators#
T	Technological innovation is referred to the number of resident and non-resident patents.	
NRV	Changes in natural resources (rents) because of supply and demand and captured as total natural resources rents: measured as GDP percentage.	
HCI	The human capital index calculates the mobilization of its citizens' professional and economic potential via returns to education.	https://www.rug.nl/ggdc-/productivity/pwt/?lang=en
RER&D	Budget provided for encouraging renewable energy in the form of research and development.	https://stats.oecd.org/#

Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

include each variable's mean, median, and range values. Also, this research utilizes a simple volatility measure in the variables under consideration. The standard deviation—the deviation or distance of observation of mean value—captures the variable's volatility. Besides, the two traditional measures are also evaluated to indicate the normality of the data. The skewness and Kurtosis are the normality measures that hold the value of 0 and 3, respectively. However, the skewness and Kurtosis indicate the data distribution throughout the selected period. Yet, the Jarque–Bera (JB) test of normality provided by Jarque and Bera (1987 is regarded as a comprehensive metric of data's normality that considers both the skewness and excess Kurtosis at the same time. The said test assumes that skewness and excess Kurtosis are zero. However, the significant statistical values could further lead to rejecting the null hypothesis. The statistical values of JB test might be achieved via the following equation:

$$JB = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right), \tag{2}$$

3.2.2. Diagnostic test

Once the normality statistics are evaluated, this study moves to the panel data estimation process. In this regard, we tested for the panel's heterogeneity and interdependence. Rapid international trade and globalization development have substantially transformed various economic and financial prospects domestically and across borders. The interdependence of countries globally has consistently risen since the industrial revolution and is yet to improve. Various financial, economic, social, environmental, energy, and technological motives lead a country involved in a connection to other countries or regions. Due to this interdependence, countries have shown similarities and differences. However, to analyze panel data, it is important to test for the issue of homogeneity since ignoring it could offer inefficient and deceptive information and outcomes (Breitung, 2005; Wei et al., 2022). This study utilizes the (M. H. Pesaran & Yamagata, 2008) SCH on a dataset for the G7 economies' panel. This test provides both the SCH values and adjusted SCH (ASCH) values, which may be structured as follows:

$$\hat{\Delta}_{SCH} = \sqrt{N(2k)^{-1}}.(N^{-1}\acute{S} - K), \tag{3}$$

$$\hat{\Delta}_{ASCH} = \sqrt{N}.\sqrt{\frac{T+1}{2K(T-K-1)}}.(N^{-1}\acute{S} - 2K), \tag{4}$$

From Equation (3), $\hat{\Delta}_{SCH}$ demonstrates the SCH statistics, and Equation (4) demonstrates $\hat{\Delta}_{ASCH}$ For ASCH statistics. The under-discussion test assumes homogenous slope coefficients across the panel. However, the hypothesis may be neglected if the $\hat{\Delta}_{SCH}$ and $\hat{\Delta}_{ASCH}$ is found statistically significant. In the same line, some reasons, including globalization and trade, enhance one economy's dependence on other countries or regions. Once the interdependence exists across the countries, this may lead to adopting an effective estimator. Yet, ignoring the CD issue may provide inconsistent results (Campello et al., 2019). This study utilizes the (Pesaran, 2004, 2021; Pesaran & Smith, 1995) CD test to analyze if the G7 economies are cross-sectionally interdependent. This assumption of this test is the cross-sectional independence across the selected panel. However, significant estimates may neglect the null proposition of the test. Besides, if the cross-sectional dependence exists in the panel data, this requires an efficient estimating approach that accounts for tackling this panel data issue. The computational equation of cross-sectional dependence may be expressed as follows:

$$CD_{Test} = \frac{\sqrt{2T}}{[N(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik}, \tag{5}$$

3.2.3. Stationarity testing

After the estimates of SCH and panel CD of the G7 economies are obtained, the predicted results validate the SCH as well as CD in the panel economies. Consequently, an efficient estimator is required to tackle the said issues; otherwise, the estimates obtained may be invalid. Therefore, this study uses the (Pesaran, 2007) cross-sectionally augmented IPS (CIPS) unit root test. Pesaran (2006) proposes a factor modeling approach to tackle cross-section dependence, where the average of cross-sections is conjoined into the model in terms of the commonly overlooked component. Based on the said technique, Pesaran, 2007 developed a unit root testing method that considers the mean and first differenced lagged cross-sections while expanding the regression model of Augmented Dickey-Fuller (ADF). Moreover, this approach proposes exact results while letting for CD even in the unbalanced panel ($N \neq T$). The cross-sectional ADF test could be provided in the regression form as follows:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \overline{y}_{t-1} + d_1 \Delta \overline{y}_t + \varepsilon_{it}, \tag{6}$$

From Equation (6), $\overline{y}_t$ reports the N observations' mean. To allow for the serial correlation problem, the stated regression [Equation (6)] may be translated with the addition of the first differenced lags of y_{it} and $\overline{y}_t$, and could be stated as follows:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \overline{y}_{t-1} + \sum_{j=0}^{n} d_{j+1} \Delta \overline{y}_{t-j} + \sum_{k=1}^{n} c_k \Delta y_{i,t-k} + \varepsilon_{it}, \tag{7}$$

Thus, Pesaran (2007) establishes the CIPS in the G7 economies via the average values of t-statistics for each unit of cross-section ($CADF_i$). Hence, the CIPS may be evaluated using Equation (8). Moreover, the CIPS unit root test undertakes the existence of unit roots in the time series. However, significant statistics could indicate the stationarity of time series.

$$CPS = N^{-1} \sum_{i=1}^{N} CADF_i \tag{8}$$

3.2.4. Cointegration testing

Once the stationarity estimates are obtained, this research analyzes the cointegration nexus between the study variables, including *EP*, *NRV*, *HCI*, *TI*, and *RER&D*. This study used the (Westerlund, 2007) error correction mechanism (ECM) to examine the long-run relationship between the variables. This test is efficient it permits for panel CD as well as SCH by integrating group as well as panel mean statistics. Moreover, both groups mean statistics as well as panel statistics could be computed while using the following equations: that is, $G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE\hat{\alpha}_i}$, and $G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}$, for mean group statistics and $P_t = \frac{\hat{\alpha}}{SE(\alpha)}$, and $P_t = T\hat{\alpha}$, for panel statistics.

3.2.5. Method of moment quantile regression (MMQR) and quantile-on-quantile regression

Koenker and Bassett (1978) first proposed a panel quantile specification approach. In this model, both the conditional variance and the mean dependent estimates are used to analyze the explanatory parameters. Since the quantile approach is an efficient estimating technique, it delivers accurate estimates when data follow the asymmetric distribution. As a result, we use the novel MMQR technique recommended by Machado and Silva (2019). The motive of this statistical method is to evaluate the distributional and heterogeneous effects of several quantiles (Sarkodie & Strezov, 2019). The scale-location variant of the restricted quantile estimates $Q_y(\tau|X)$ may be expressed as follows:

$$Y_{it} = \theta_i + \vartheta X_{it} + \left(\delta_i + \rho \acute{Z}_{it}\right)\mu_{it}, \tag{9}$$

where Equation (9) demonstrates that the probability value of $P\left(\delta_i + \rho \acute{Z}_{it} > 0\right) = 1$. However, the θ, ϑ, δ, and ρ are the predicted parameters. Additionally, i in the subscript designates fixed effect factors by θ_i and δ_i, $i = 1,2,3,\ldots,$ n. Lastly, Z designates the k-vector of the documented X elements, which is conversions based on the variation with component $\mathbb{I}$ and could be written as:

$$Z_{\mathbb{I}} = Z_{\mathbb{I}}(X), \quad \mathbb{I} = \quad 1, \quad 2, \quad \ldots, \quad k \tag{10}$$

From the above equation, is could be noted that X_{it} is impartially and identically spread for each specific i and t. Likewise, μ_{it} is orthogonal to X_{it} and could be

distributed across fixed cross-sections and time (Machado & Silva, 2019), supportive of stabilizing the rest of the factors and preventing excessive external behavior. Hence, the priory given Equation (1) could adopt the following shape:

$$Q_y(\tau|X_{it}) = (\theta_i + \delta_i \ q(\tau)) + \vartheta X_{it} + \rho \acute{Z}_{it} q(\tau), \tag{11}$$

Here, X_{it} denotes the vector of independent variables, including *NRV*, *HCI*, *TI*, and *RER&D*, where the natural log of these variables are taken in the empirical examination. From Equation (11), $Q_y(\tau|X_{it})$ designates the distribution of quantiles for the key (dependent) variable, which is *GDP* in this case and could be computed as reliant on the location of the dependent variable X_{it}. Besides, $-\theta_i \ (\tau) \equiv \theta_i + \delta_i \ q(\tau)$, is the scaler factor, which is quantile's τ fixed effect for particular *i*. Contrary to prevailing least-square fixed effects, the specific influence does not hold any transforms the intercept. The heterogeneous impact is vulnerable to shift and the reliant distribution throughout quantiles because of the time-invariant parameters' characteristics. Moreover, $q(\tau)$ indicates the τ-th quantile's sample, which is considered four in this research, that is, 0.25, 0.50, 0.75, and 0.95. The quantile's equation utilized for the determination of each quantile is presented as follows:

$$\min_q \sum_i \sum_t \gamma_\tau \Big(R_{it} - \big(\delta_i + \rho \acute{Z}_{it}\big) q \Big), \tag{12}$$

Where $\gamma_\tau(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$, reflects the checking expression.

The Quantile-on-Quantile (QQ) regression method of (Sim & Zhou, 2015) is also employed. This approach compares one variable's quantile(s) to the quantile(s) of another variable. It also combines two approaches: quantile regression (examining the influence of explanatory variables on response variable's quantiles) and non-parametric regression. Koenker and Bassett (1978) offered an enriched version of the regression inquiry where the variable's mean is contrasted to the other variable's mean. Quantile regression helps account for a larger fraction of quantile fluctuation, allowing experts to forecast more correctly. According to Cleveland (1979), one of the drawbacks of classical regression is the reduction of data dimensionality to match a linear expression, reducing prediction accuracy. The ability to anticipate increases when the QQ technique compares the quantiles of regressors' quantiles to a response variable's quantiles (S. J. H. Shahzad et al., 2017). Further, a robustness check is performed through a fully modified regression (FMOLS).

4. Results and discussion

4.1. Results

This study initiates empirical estimations by exploring the normality and descriptive stats of the G-7 economies and is provided in Table 2. Each study variable's mean and median values are roughly the same, having a small difference, except for the RER&D. On the other hand, a substantial difference is noted in the range (minimum–maximum) values, indicating that the values vary across time. To analyze whether the variables are volatile across time, the standard deviation is a simple measure that indicates whether the factors are volatile or not. Regarding volatility, all the study variables showed variabilities. However, NRV is found to be the highest after RER&D. This indicates that the

Table 2. Normality and descriptive statistics.

	EP	*NRV*	*HCI*	*TI*	*RER&D*
Mean	12.51086	0.627850	3.370263	4.714653	14.47343
Median	12.42631	0.135007	3.482147	4.549996	12.80594
Maximum	13.26361	5.007270	3.757822	5.793408	51.47142
Minimum	12.03306	0.010885	2.553845	3.872331	0.574575
Std. Dev.	0.311627	0.939987	0.318756	0.589367	9.603008
Skewness	0.892402	2.198113	−0.781315	0.502365	0.986090
Kurtosis	2.973178	7.855834	2.443798	1.884557	4.170966
Jarque-Bera	28.80894	387.9412	24.87521	20.37719	47.56510
Probability	0.000001	0.000000	0.000004	0.000038	0.000000

Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

Table 3. Diagnostic tests.

Slope heterogeneity test	Statistics
$\tilde{\Delta}$	15.253***
$\tilde{\Delta}_{\text{Adjusted}}$	16.985***
Cross-section dependence	
EP	23.497***
NRV	7.946***
HCI	25.121***
TI	6.74***
RER&D	11.086***

Note: The level of significance is represented by ***(1%), **(5%), and *(10%).
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

variable NR is volatile across the selected period in the G-7 economies. Further, the skewness and Kurtosis statistics are also computed to decide the normality distribution of the data, which revealed that the variables are non-normally distributed. The statistical values of Jarque and Bera (1987) normality test are significant at 1, 5, and 10% levels. This provides the rejects of the null proposition: therefore, it is established that the selected variables are abnormal in distribution.

Table 3 provides the estimated outcomes of panel cross-section interdependence as well as heterogeneity. The empirical findings report that SCH and ASCH values are statistically significant at all 1%, 5%, and 10% levels. Hence, the proposition of Pesaran and Yamagata (2008) SCH test: homogenous coefficients may be neglected. Since the industrial revolution, globalization and cross-boarders trade have been rapidly developing, enhancing the dependence of one nation on other countries. The primary motive for this dependency on other countries is attaining various economic, financial, political, technological, and social objectives (Hmaittane et al., 2019). Nonetheless, cross-section dependency may have a substantial part in developing an economy. However, ignoring such issues in an econometric investigation could lead to biased information (Breitung, 2005; Wei et al., 2022). We employed (Pesaran, 2004, 2021; Pesaran & Smith, 1995) CD test, and the empirical findings validate the cross-section dependence across the variables. EP, NRV, HCI, TI, and renewable energy R&D are interdependent across G-7 economies.

Since the slope coefficients are found heterogeneous and cross-sectional dependency between the variables prevails. This research applied the (Pesaran, 2007) CIPS test, an efficient estimator that allows for panel estimations issues such as slope heterogeneity and cross-section interdependence. Table 4 provides the estimated findings of the CIPS

Table 4. Stationarity test.

	Intercept and trend	
Variables	I(0)	I(1)
EP	−1.875	−4.012***
NRV	−2.851**	−4.904***
HCI	0.461	−2.757*
TI	−2.595	5.161***
RER&D	−2.851**	−5.390***

Note: The level of significance is represented by ***(1%), **(5%), and *(10%). %. I(0) shows the level, and I(1) shows the first difference.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

Table 5. Cointegration outcomes.

Statistics	Value	Z-value
G_t	−3.589***	−4.141
G_a	−15.481**	−2.084
P_t	−8.572***	−3.390
P_a	−14.233***	−2.935

Note: The level of significance is represented by ***(1%), **(5%), and *(10%).
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

Table 6. Estimates of MMQR.

			Quantiles			
Dep. Var.: E *P*	Location	Scale	$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.95}$
NRV	−0.018***	−0.002	−0.016**	−0.018***	−0.019***	−0.021***
HCI	0.340***	0.024	0.319***	0.342***	0.362***	0.384***
T	0.240***	0.0002	0.240***	0.240***	0.241***	0.241***
RER&D	0.009**	−0.008***	0.016***	0.009*	0.0024	−0.005
Constant	10.222***	0.039	10.256***	10.218***	10.186***	10.149***

Note: The level of significance is represented by ***(1%), **(5%), and *(10%).
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

unit root test for the leveled I(0) and first differenced I(1) data. The examined results show that only two variables, i.e., NRV and RER&D, are significant at I(0)—stationary, while EP, HCI, and TI are insignificant. At the same time, all the variables are stationary at 1%, 5%, and 10% levels at I(1). Since all the variables are observed stationary at I(1), we can examine the cointegration association between the study variables.

Table 5 provides empirical outcomes of Westerlund (2007) cointegration. The test supposes the ECT = 0 in a conditional error correction model. The results after estimation for group mean (G_t and G_a) and panel mean (P_t and P_a) are significant at 1%. Therefore, the results demonstrate that both groups' error correction is valid. Hence, the cointegration connection prevails between EP, NRV, HCI, TI, and RER&D.

Since the abnormal distribution of each variable's data allows for estimating the methods of moments quantile regression, the empirical results are indicated in Table 6. The estimated result of the said regression provides the predicted value of every variable at a given scale, location, and quantile. The current study used four quantiles ($Q_{0.25}$, $Q_{0.50}$, $Q_{0.75}$, and $Q_{0.95}$), where the focus variable, i.e., NRV captured by total NR rents, shows a negative influence on EP of the G-7 economies. However, the magnitude of the negative influence increases and is more significant when shifting from the lower

quantile to the upper quantile. A percent increase in NRV causes a reduction of 0.016 − 0.021% at 5% and 10% levels. This negative influence demonstrates that NRV is non-favorable for economic growth, similar to what (Benramdane, 2017; Hayat & Tahir, 2021; Q. Ma et al., 2021; Sun & Wang, 2021) provided.

On the other hand, HCI and TI are positively associated with EP in G-7 countries. Similar to NRV, the magnitude of influence is noted as increasing, shifting from lower ($Q_{0.25}$) to medium—($Q_{0.50}$ and $Q_{0.75}$) to upper ($Q_{0.95}$) quantiles. One percent rise in the HCI augments EP by 0.319 − 0.384% at a 1% level at all the quantiles. The examined outcomes asserted that the quality of education, health, and well-being enhancement is positively connected to the region's increased EP. From the existing literature, Dasci Sonmez and Cemaloglu (2021), Khan et al. (2019) and Yang (2020) have provided consistent findings on the progressive impact of HCI on growth and development in various countries. Regarding TI, a one percent increase significantly enhances the EP of the G-7 countries by 0.240—241% at a level of 0.01. The magnitude of TI's positive impact increases at a lower phase than the NRV and HCI while moving on or after the lower-to-upper quantiles. These findings are supported by the conclusions of Broughel and Thierer (2019) and Kihombo et al. (2021), who provided empirical evidence that enhancement in TI is positively connected to the promotion of higher education economic growth in various countries.

Lastly, renewable energy research and development significantly impact the EP of the study panel. However, this influence is positive and statistically significant only in the first two ($Q_{0.25}$, $Q_{0.50}$) quantiles. At the same time, the third ($Q_{0.75}$) and the fourth ($Q_{0.95}$) quantiles indicate the positive insignificant and insignificant negative influence of RER&D on EP. It is worth mentioning that both the magnitude and significance level of RER&D shrink from $Q_{0.25}$ to $Q_{0.50}$. Concerning the positive effect of research and development budget or investment on economic growth, earlier studies by Guloglu and Tekin (2012) and Silaghi et al. (2014) have provided consistent results. Besides each explanatory variable's exact influence on EP, this influence is also visualized in Figure 1.

Apart from the exact impact of regressors on EP, this study also tried exploring the nexus between NRV and EP for each G-7 economy via a novel Quantile-on-Quantile (QQ) regression. Concerning Figures 2, 3, 4, 7, and 8, the estimated results of QQ regression are displayed for Canada, France, Germany, the UK, and the USA, respectively. These figures show that although a positive link between NRV, as reported by the yellow-red color. However, the negative association is greater than that of the positive one, as reported by the green and blue color of the figures. Yet the positive link between the two variables is found in lower-to-medium quantiles, whereas the negative connection is evidenced in the middle-to-upper quantiles. On the other hand, Figures 5 and 6 asserted a mixed link between NRV and EP in Italy and Japan, respectively. Yet the positive association between the two is more robust in the lower and upper quantiles. However, the negative connection between the two variables is noted in medium quantiles, particularly between 0.2 and 0.8 quantiles, which are greater than those of the lower and upper quantiles. Therefore, the negative connection between EP and NRV is greater when the entire quantiles are considered. Hence, the negative link between NRV and EP is evident in all the G-7 countries, which validates the earlier empirical findings of MMQR.

Once the results are obtained via the moment's quantile regression and quantile-on-quantile regression method, this study utilizes the FMOLS, and DOLS approaches to test

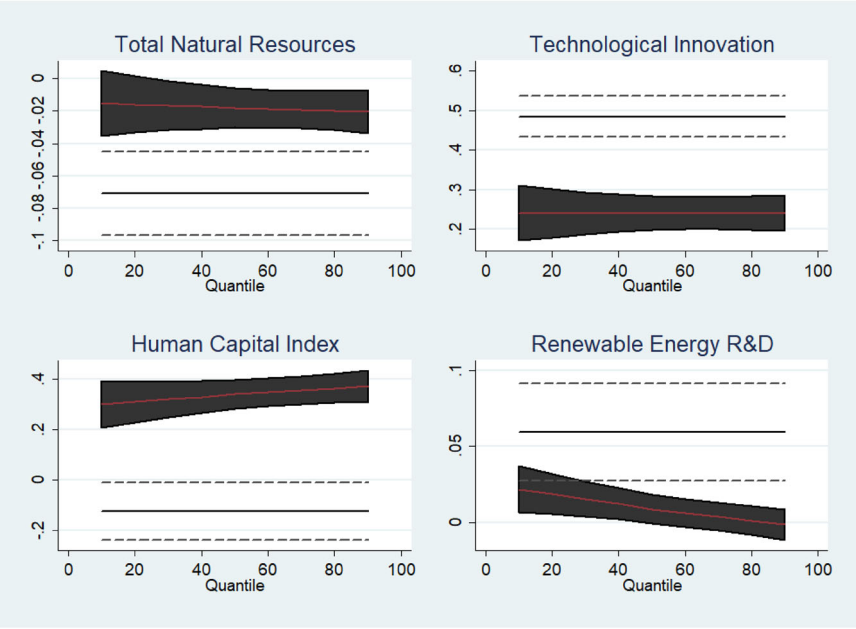

Figure 1. Graphical Outcomes of method of moment quantile regression.
Source: Author's calculations.
Data Availability: The data are available on request from the corresponding author.

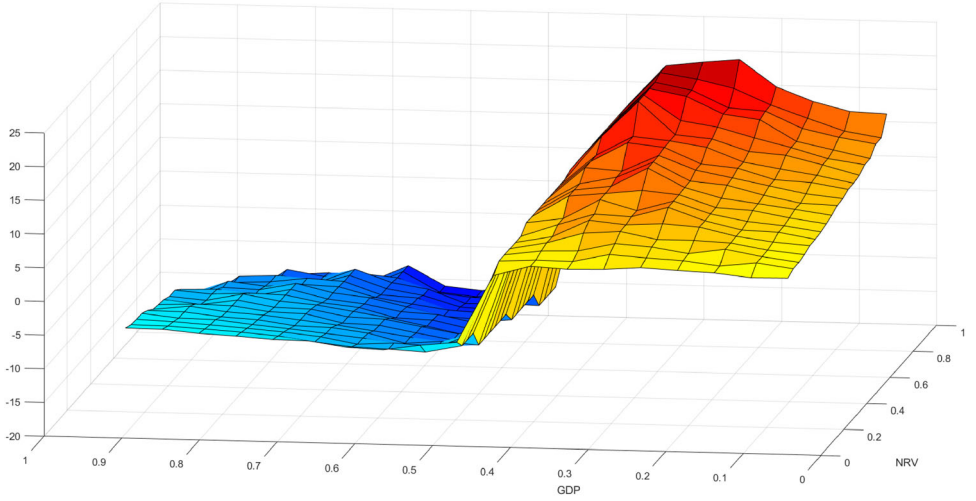

Figure 2. Quantile on quantile regression for Canada.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

the robustness of the models in consideration. The estimated results of both the parametric and non-parametric approaches are given in Table 7. The Estimated results have validated the direction of the influence, which is negative for NRV, positive for HCI and TI, and significant at 1, 5, and 10% levels. On the other hand, the RER&D variable suggests an insignificant connection with the EP of the G-7 economies, which is consistent with

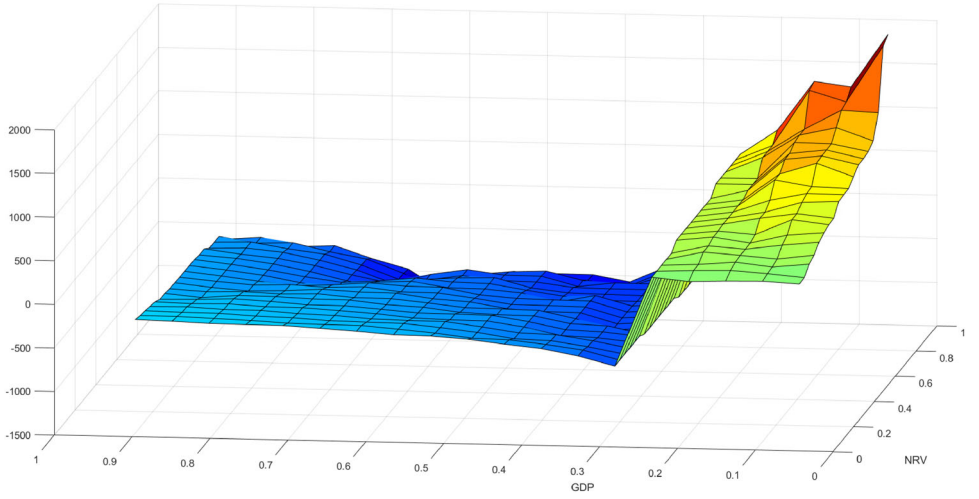

Figure 3. Quantile on quantile regression for France.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

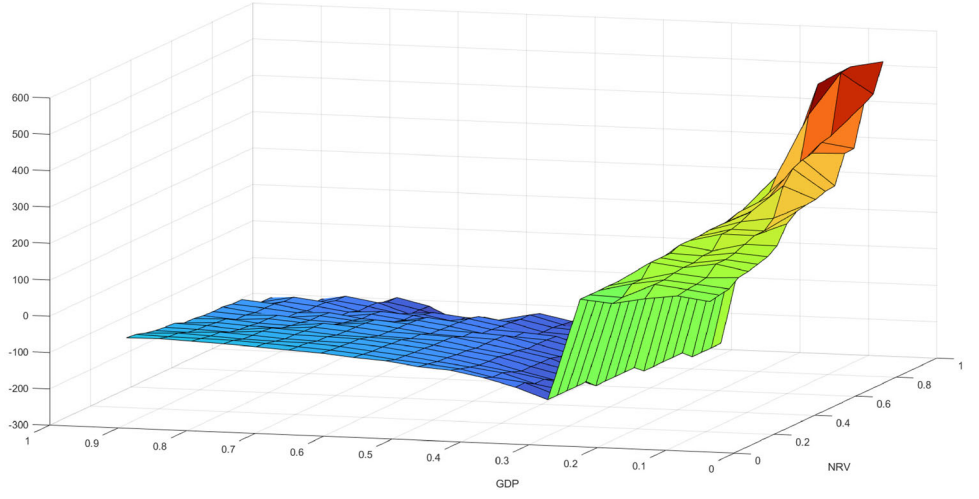

Figure 4. Quantile on quantile regression for Germany.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

the last two quantiles ($Q_{0.75}$ and $Q_{0.95}$). Nonetheless, the magnitude values are slightly different; the direction of association remained the same. Hence, the findings of FMOLS and DOLS verified that the model under consideration is robust.

4.2 Discussion

To analyze whether the stationary and abnormally distributed explanatory variables exhibit any influence on the EP of the G-7 countries, this study employed the MMQR technique. The estimated findings asserted that NRV adversely affects EP in

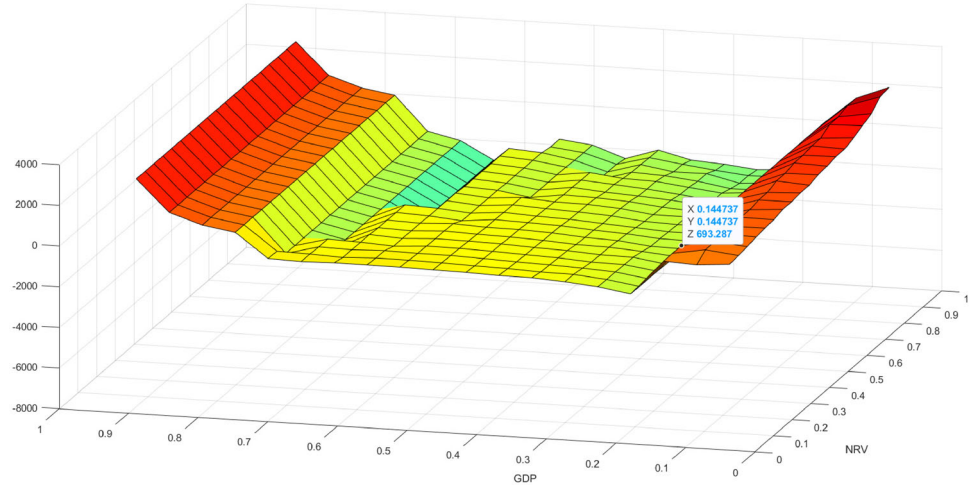

Figure 5. Quantile on quantile regression for Italy.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

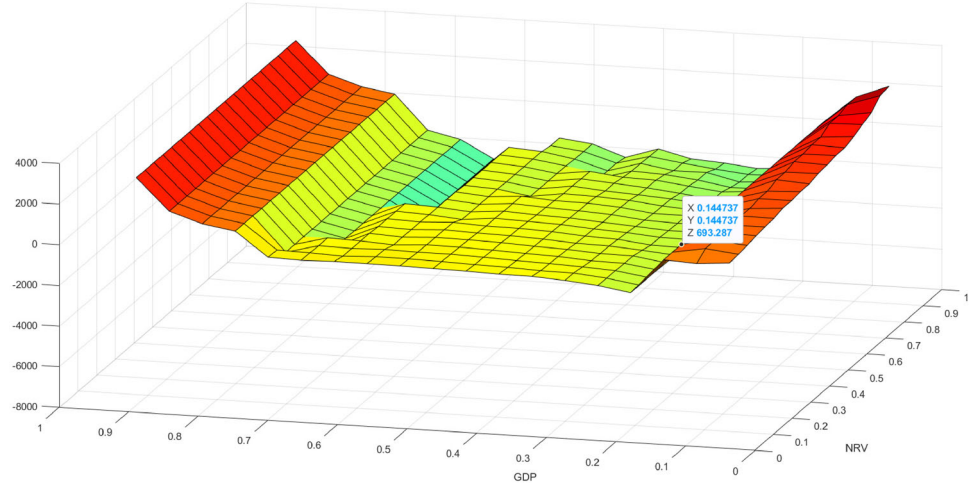

Figure 6. Quantile on quantile regression for Japan.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

the study panel economies, consistent with the earlier findings of Benramdane (2017) and Hayat and Tahir (2021). Specifically, an increase in the NRV enhances uncertainty in the business and investment market, leading to the postponement of investment, businesses, and industrial production due to uncertainty of future outcomes. However, postponement in these sectors, a significant contributing factor earlier, is now a hurdle to promoting and encouraging regional economic growth. Since the earlier studies validate the persistence of instability in NR across the period (Ma et al., 2021; Sun & Wang, 2021), empirical findings identify the negative association

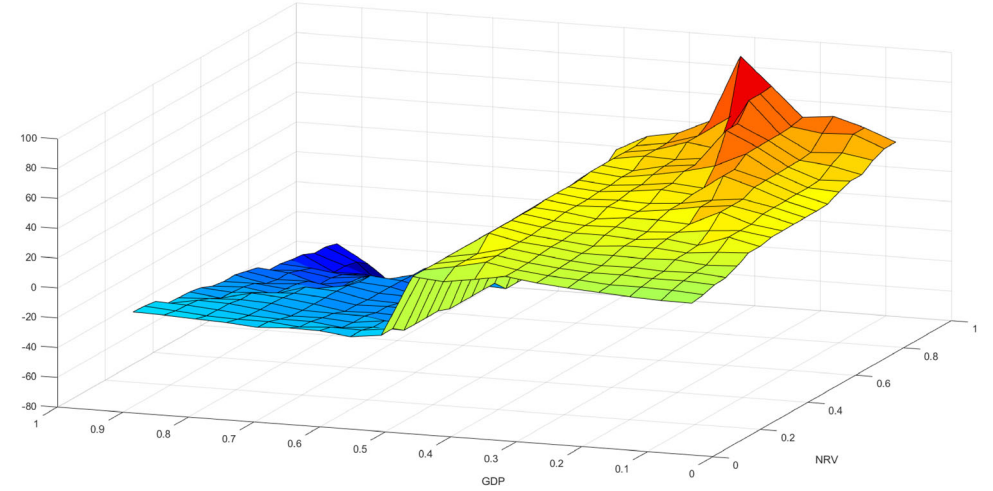

Figure 7. Quantile on quantile regression for UK.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

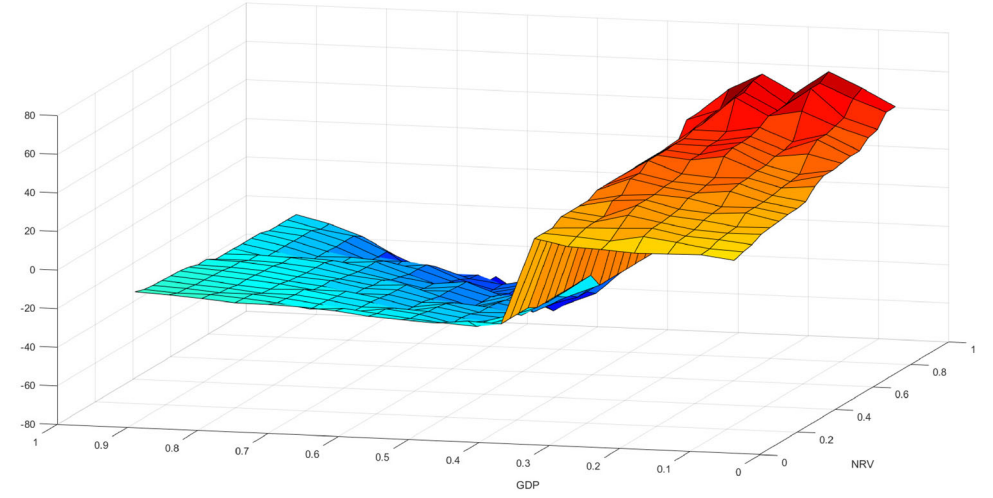

Figure 8. Quantile on quantile regression for USA.
Note: The *x*-axis reports NRV, *y*-axis indicates GDP, and the *z*-axis shows the coefficient values.
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

Table 7. Robustness test.

Variable	FMOLS			DOLS		
Variable	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
TNRR	−0.026***	0.009121	0.0044	−0.005	0.010450	0.6027
HCI	0.348***	0.035793	0.0000	0.235***	0.047473	0.0000
TI	0.242***	0.046743	0.0000	0.215***	0.059146	0.0004
RERD	0.000275	0.000678	0.6857	0.001239	0.000929	0.1855
R^2		0.990022			0.997937	
Adjusted R^2		0.989521			0.996017	

Note: The level of significance is represented by ***(1%), **(5%), and *(10%).
Source: Author's calculation.
Data Availability: The data are available on request from the corresponding author.

of these variables in the long run. Therefore, NRV is detrimental to EP. Besides the overall influence of NRV on EP, this study is also evident for the specific (each G-7) country. The results indicate that the negative association between the two is valid for each cross-section of the designated panel economies confirmed via QQ regression.

In addition, TI, HCI development, and renewable energy research and development are contributing factors to EP. Regarding HCI and improved education, skills, and health level, individuals tend to efficiently utilize various energy resources in every economic sector. Therefore, the level of production increases, and the industrial sector expands, which creates more employment and enhances the circulation of money. This cycle reduces the burden on the economy and consequently promotes the region's EP. Since current findings reveal the positive nexus of HCI and EP, many studies provide consistent results (Dasci Sonmez & Cemaloglu, 2021; Khan et al., 2019; Yang, 2020). Once the level of HCI improves, the culture of research and development and TI is also promoted. Improvement in research and development is a significant factor of innovation in both industrial as well as related environmental technologies, which not only promote the efficient utilization of energy resources but also reduces environmental degradation by curbing emission pollution in the region—decoupling economic growth from emissions (Wang & Wang, 2019; Wang & Zhang, 2020; Zafar et al., 2019). Current findings regarding the positive and significant influence of TI and renewable energy R&D are consistent with the existing literature (Broughel & Thierer, 2019; Guloglu & Tekin, 2012; Kihombo et al., 2021; Silaghi et al., 2014).

5. Conclusion and policy recommendations

5.1. Conclusion

This study considers the influence of NRV, HCI index, TI, and renewable energy-related R&D on EP of the G-7 economies. The results of novel non-parametric (i.e., MMQR and QQ regression) approaches reveal that NRV is negatively linked with the EP in each G-7 country and the panel. On the other hand, HCI, TI, and renewable energy R&D significantly enhance EP in the region. The FMOLS approach validates the robustness of the results.

5.2. Policy recommendations

Based on the empirical findings, it is explored that NRV is detrimental to EP in the G-7 economies. Therefore, these economies need appropriate policy attention towards the volatility abatement in NR. Specifically, this study recommends the practice of stringent policies regarding NR. The NR price ceiling or price-fixing could mitigate the panic of uncertainty in the NR market, which eventually boosts EP in the region due to investors' attraction. Although many factors lead to NRV; yet, the demand and supply of NR matter the most. The G-7 countries are heavily reliant on NR utilization, due to which NR (energy in the shape of fossil fuel, in particular) and their prices are non-stable. Hence, alternative approaches, such as renewable energy consumption, will be promoted along with the sustainable use of NR to maintain its prices, which could ultimately lead to the encouragement of EP. Additionally, investment in HCI, such as education and health,

must be encouraged. This will enhance the skill level, lead to efficient utilization of NR, reduce possible NR waste and leakage, and lead to environmental sustainability along with the enhancement in EP. Besides, a need for revised policies regarding TI and R&D has been observed. Investment in such fields will promote the efficient utilization of resources and encourage the use of non-natural resources (renewables), which could reduce the demand for natural resources and assist in stabilizing volatility. Consequently, enhanced investment in technology and R&D could help expand economic and industrial sectors—leading to higher EP and growth in the G-7 region.

The current study explores the nexus of NRV and EP by the MMQR. However, future studies can analyze the nature of the relationship by using more relationships. To provide further meaningful insights, this study can be extended by analyzing the relationship of components of NR volatility to EP. Also, future studies are directed to examine the influence of other economic, environmental, and energy indicators on the EP of the G-7 and other countries or regions.

Notes

1. See for instance: Auty (1993), Caselli and Cunningham (2009), Badeeb et al. (2017), Asif et al. (2020), and Khan et al. (2020).
2. See for e.g., Hayat and Tahir (2021), Dogan et al. (2020), Hussain et al. (2020).

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ORCID

Nafeesa Mughal http://orcid.org/0000-0002-3604-2611
Rinat Zhanbayev http://orcid.org/0000-0001-7791-9080
Iskandar Muda http://orcid.org/0000-0001-6478-9934

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