Resources Policy 86 (2023) 104214

Contents lists available at ScienceDirect

Resources Policy

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

How does economic complexity affect natural resource extraction in resource rich countries?

Shajara Ul-Durar[a,b,*], Noman Arshed[c], Awais Anwar[c], Arshian Sharif[d], Wei Liu[e,**]

[a] University of Sunderland, The School of Business Management, Edinburgh Building, Chester Road, Sunderland, SR1 3SD, UK
[b] Durham University, Business School, Mill Hill Lane, Durham, DH1 3LB, UK
[c] Department of Economics, Division of Management and Administrative Science, University of Education Lahore, Pakistan
[d] Department of Economics and Finance, Sunway University, Malaysia
[e] Business School, Qingdao University, Qingdao, 266071, China

ARTICLE INFO

Keywords:
Quadratic function
Quantile ARDL regression
Productive capacity index

ABSTRACT

Several studies debate whether natural resources benefit or hurt an economy. In natural resource-rich economies researchers cannot conclude it. This study examines the relationship between natural resource rent, economic complexity, clean technology, and natural resource productivity capacity in 20 resource-rich economies from 2000 to 2021. Coal, oil, minerals, natural gases, and forest rents are disaggregated in the study. The economic complexity curvilinear function illustrates the inverse U-shaped relationship under the environmental Kuznets curve (EKC) or the U-shaped relationship under load capacity curve (LCC) between economic complexity and natural resources rent. This study hypothesizes that economic complexity increases resource extraction curvilinearly, changing resource rents which may have implications in the transition towards clean energy under COP27 to achieve SDGs. The study shows the marginal effects of economic complexity at different levels of complexity and resource extraction using quadratic and quantile functions. This study first examines resource extraction quantiles. Economic complexity raises forest, coal, and mineral rents at low resource extraction. Economic complexity lowers forest, gas, oil, coal, and mineral rents at high resource extraction. This study describes the curvilinear function. At the median resource extraction level, economic complexity has an inverted U-shaped effect on forest, mineral, and coal rents and a U-shaped effect on gas and oil rents. This implies that an increase in economic complexity can be targeted which may reduce reliance on forests, minerals, and coal while reducing reliance on gas and oil, government effort, green technology, and productive capacity needed to be pursued.

1. Introduction

Natural resources are essential to meeting sustainable development goals (SDGs). Sustainable development requires responsible natural resource management which the SDGs promote. Natural resources underpin economies, societies, and well-being. Over-exploitation, pollution, and other unsustainable practices have caused environmental degradation, biodiversity loss, and climate change (Yasmeen et al., 2019). Sustainable development requires protecting and managing natural resources like water, forests, minerals, and wildlife. The SDGs aim to ensure water availability and sustainable management for future generations in addition to aiming to urgently combat climate change and its effects by reducing greenhouse gas emissions and promoting renewable energy. The SDGs require sustainable use of natural resources like fossil fuels which cause climate change. The SDGs and sustainable development depend on the responsible use and management of natural resources (Destek et al., 2018; Guo et al., 2019; Ahmed et al., 2020). In addition, Russia, Colombia, and Kuwait contain the highest ratios of natural resources as a percentage of GDP. However, some advanced economies such as Finland, Australia, and France exhibit low ratios of natural resources. COP27 urges the nations to develop strategies toward a clean energy transition. Under this premise, a study exploring the causes of resource extraction based on the economic production structure could help make a sustainable resource policy.

* Corresponding author. University of Sunderland, The School of Business Management, Edinburgh Building, Chester Road, Sunderland, SR1 3SD, UK.
** Corresponding author.
E-mail addresses: Shajara.ul-durar@sunderland.ac.uk (S. Ul-Durar), noman.arshed@ue.edu.pk (N. Arshed), awais.anwar@ue.edu.pk (A. Anwar), arshians@sunway.edu.my (A. Sharif), wei.liu@qdu.edu.cn (W. Liu).

https://doi.org/10.1016/j.resourpol.2023.104214
Received 7 May 2023; Received in revised form 22 August 2023; Accepted 25 September 2023
Available online 30 September 2023

Production changes reflect economic complexity according to literature on several economies. According to several studies, the ECI (Economic Complexity Index) quantifies the knowledge embodied in a country's product system (Hausmann et al., 2007; Hidalgo et al., 2007; Hidalgo and Hausmann, 2009). However, economic structure changes link economic development which diverges into various consumption and production methods (Albarracín et al., 2019). Moreover, economic complexity has significant effects on natural resources. Economic complexity-led changes in natural resource utilisation can help mitigate climate change and environmental quality. Economic complexity may also boost natural resource demand. Complex economies depend more on natural resources for growth. Energy sources can be renewable or nonrenewable. Thus, demand for these resources may rise thus putting pressure on ecosystems and possibly causing resource overuse or depletion (Charfeddine, 2017; Ahmed et al., 2020). Economic complexity may also spur innovation and the development of new technologies that reduce natural resource use or mitigate their effects. Renewable energy and energy efficiency technologies may reduce fossil fuel use and economic activity's environmental impact, for instance (Alvarado et al., 2021). So nations pursuing the complexity policy may experience an initial increase and then a decrease in the utilisation of natural resources following an inverted U-shaped relationship discussed under the environment Kuznets curve (EKC).

Natural resources are also vulnerable to volatile commodity markets. Oil, gas, and mineral-dependent nations are vulnerable to price fluctuations which can hurt their economies. Resource-dependent economies face uncertainty and risk due to this boom-bust cycle. Corruption, bribery, and other illegal activities often accompany natural resource trade and extraction, causing social and economic issues. However, solving these issues requires sustainable resource management, investment in alternative energy and energy efficiency, and transparency and good governance in natural resource management. Governments must invest in infrastructure and human capital to develop natural resources sustainably and equitably. Finally, addressing climate change is essential to ensuring that natural resources continue to provide economic benefits without worsening environmental issues (Khan et al., 2018; Ndikumana and Sarr, 2019; Zafar et al., 2019).

The prime objective of the current study is to examine the association between natural resources rent, economic complexity, and clean technology among several economies containing a high amount of natural resources from 2000 to 2021. Most empirical studies have linked natural resources with growth and environmental outcomes but very few have explored its determinants. The current study contributes to the existing literature in the subsequent imperative ways.

Firstly, existing studies accentuated that economic complexity reflects the changes in production plans (Hidalgo and Hausmann, 2009; Hausmann et al., 2014). However, economic development is interlinked with structural fluctuations among several economies derived from the changes in production and consumption plans. Therefore, these fluctuations represent economic complexity having an important relationship with natural resource extraction required for production. The economic complexity and natural resources consumption association becomes more worthwhile in the context of climate change and environment issues. This study explores the non-linear patterns to discover whether the transition toward complex economies changes how nations consume natural resources.

Secondly, the association between productive capacities and extracted input material for consumption has not been extensively studied in the literature, something that would help to attain SDGs. Therefore, it is necessary to materialize the integrated methodology to development at an international and national level. Moreover, increasing the efficiency of resources ensures the sustainable management of material resources. These components play an essential role in the growth policy of the world or particular region. The present study incorporates a production capacity index (PCI) based on six sub-indicators including transportation, energy, infrastructure, human capital, natural resources, and the public and private transformation in production. It also apprehends the impact of productive capacity on the sustainability of resources (Praveen et al., 2020; Sun et al., 2022; Xin et al., 2023).

Thirdly, this study applies the state of the art panel quantile ARDL model with dynamic fixed effect specification to estimate effects at the median and other locations on the dependent variable distribution which are robust to outliers, unobserved heterogeneity, and autocorrelation in the data. This model can estimate long run and short run effects in the same way as panel ARDL models but with the added ability to handle non-normal variables. This novel approach helps in tracing the non-linear effect at different levels of resource extraction to devise optimal resource policy.

The rest of the paper is planned as follows: in Section 2 the literature review is discussed, in Section 3, the theoretical framework is explained, in the fourth section the data description and estimation technique is elaborated upon while the fifth section presents and discusses the empirical results. The final section provides the conclusion.

2. Literature review

According to Canh and Thong (2020) and Canh et al. (2020), natural resources can both boost and hinder economic growth. A study of 25 developing Asian countries by Huang et al. (2020) showed a positive effect of forest, mineral, and oil rent on economic growth. Havranek et al. (2016) found 40% negative effects, 40% no effect, and 20% positive effects in a meta-analysis of economic growth and natural resources. Natural resources have been shown to help economies converge but Gylfason (2001) found an inverse relationship between economic progress and resource rents in 65 resource-rich countries from 1965 to 1988. Danish et al. (2019), Dong et al. (2019), and Erum and Hussain (2019) contributed to the mixed results. Climate change has increased economic interest in natural resource rents. Le and Le Van (2018) and Merino-Saum et al. (2018) stressed the importance of studying natural resource rents from different angles. Kalkuhl and Brecha (2013) suggest that reducing fossil fuel demand may be more effective than reducing fossil fuel rents which may have the opposite effect by increasing rents due to scarcity of resources. Gerelmaa and Kotani (2016) claimed that the resource curse and 'Dutch disease' applied between 1970 and 1990 but not from 1990 to 2010 due to manufacturing sector growth. Vaz (2017) suggests that vertical integration between manufacturing and energy could affect rents.

Canh and Dinh Thanh (2020) and Le et al. (2020) supported the idea that export diversity indicates economic development. However, Hausmann et al. (2007), Hausmann et al. (2014), Hidalgo et al. (2007), and Hidalgo and Hausmann (2009) have introduced the ECI as a measure of national export diversification. These studies show that many economies prioritise economic production over export diversification. Higher ECI values indicate greater diversification and economic resilience (Hausmann et al., 2014). Increased production system diversity and quality may affect natural resource rents from two angles. First, diversifying and improving production may increase demand for production inputs, including natural resources. Second, economic complexity can create new economic activities in emerging areas or with innovative products, stimulating economic development and potentially increasing natural resource rents through rent-seeking behaviour. Thus, economic complexity may increase natural resource rents (Hodler, 2006; Pintea and Thompson, 2007).

Empirical studies have indirectly explored the link between ECI and resource extraction. Studies have indicated that there can be a positive effect of ECI on resource extraction (Hodler, 2006; Pintea and Thompson, 2007), and ECI can also lead to substitution towards sustainable production practices reducing resource extraction (Hausmann et al., 2014). This study fills this gap by using Haans et al. (2016) method to utilize a quadratic function to assess how competing effects transition from one to another.

Yu et al. (2015) and Peck and Parker (2016)have shown that natural resources are essential to national, economic, and social development but its extensive utilitzation can increase environmental degradation as evidenced in G-20 countries (Lei et al., 2022). Rosen (2013) noted that industrialization and population growth have caused extensive exploitation of natural resources thereby degrading resource bases. According to Hall and Helmers (2013) and Sonnenschein and Mundaca (2016), inefficient resource use and environmental degradation can hinder economic growth. Thus, innovative green technologies, energy conservation and emission reduction, and economic transformation toward sustainable natural resource utilisation are necessary to improve natural resource utilisation efficiency. Gosens and Lu (2013) and Hyard (2013) support this view.

Numerous studies have examined how regional organisations, economic activity, and energy systems interact. Balta-Ozkan et al. (2015) proposed effective and equitable urban and regional planning policies for regional energy transformation. Xu and Lin (2017) empirically analyzed China's steel industry and found that energy efficiency is crucial to green development. Emodi et al. (2017) examined energy policies and future energy demand factors in Nigeria using scenario analysis. Wang et al. (2015) identified China's carbon emission drivers which can help develop low-carbon policies. According to empirical findings, energy structure,q and low energy efficiency significantly increase carbon emissions. Fernando and Xin (2017) and Wang et al. (2017) emphasize the need to analyse technologies, systems, energy use, and carbon emissions to maximise natural resource utilisation efficiency. According to Huysveld et al. (2015) and Yu et al. (2016), natural resource utilisation efficiency must be improved. Existing research shows a gap in understanding the relationship between green technological innovation, low-carbon economic development, and natural resource utilisation efficiency (Sueyoshi and Goto, 2014; Purchase et al., 2016). For instance, research on natural resource efficiency improvement strategies and green technological innovation is incomplete. Green technological innovation's effects on natural resource efficiency need further study.

According to Doğan et al. (2019), a country's productivity, which depends on its knowledge, skills, and sophistication, can significantly affect environmental parameters. Sun et al. (2022) noted that while the current literature has used indicators like export concentration, economic complexity, trade diversification, and industrial structure to portray a nation's economic structure regarding productivity, these metrics only provide a limited view. According to UNCTAD (2021), the UN recently introduced the Productive Capacity Index (PCI) to measure a country's economic structure. UNCTAD (2006) defines productive capacity as a nation's ability to produce goods and services through economic progress and structural change. A higher PCI value indicates a more productive economic structure while a lower value indicates the opposite. All PCI components are connected to nature. According to Brandt et al. (2017), natural resource value in manufacturing is often overlooked in economic models, but it is crucial for long-term economic progress and adaptability to attain new production levels which could impact environmental standards. Fafchamps and Quisumbing (1999) showed that human capital boosts productivity and economic development. Human capital can increase nonrenewable resource consumption and pollution until a certain threshold is reached, after which eco-consciousness rises, leading to the adoption of eco-friendly technologies and a reduction in carbon emissions through resource conservation and better management as suggested by Hanif et al. (2020) and Khan et al. (2022). In structurally weak economies, energy use for production is difficult.

However, emerging businesses or aspiring entrepreneurs may prefer developing their entrepreneurial ventures with limited reliance on natural resource rents due to cost savings and social support. Increasing entrepreneurial activity and technological innovation are strongly correlated (Ben Youssef et al., 2018; Douglas and Prentice, 2019). This trend encourages entrepreneurs to launch new products with improved functionality and cost-effective production methods, fostering innovation (Matthews and Brueggemann, 2015; Fuentelsaz et al., 2018). Entrepreneurs create new products with less reliance on expensive natural resources and external factors. An increase in ECI is associated with a higher-quality production system and may increase efficiency in activities that require fewer natural resource rents, benefiting the economy (Gerelmaa and Kotani, 2016; Balsalobre-Lorente et al., 2018; Le and Le Van, 2018).

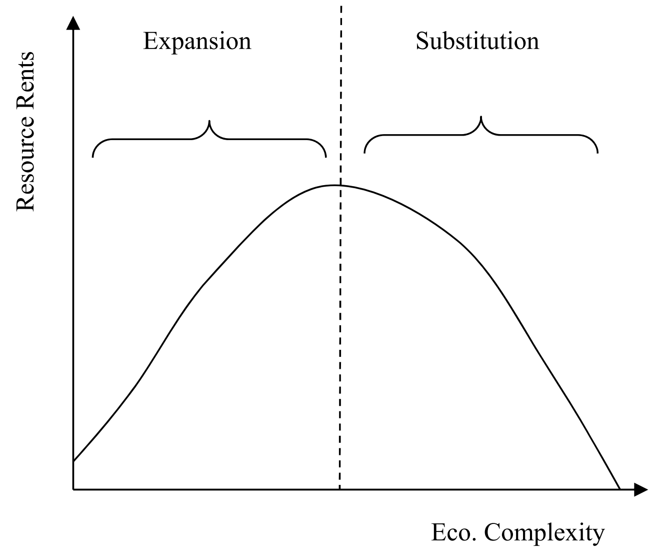

Fig. 1. Inverted U-shaped economic complexity and resource rents relationship.

3. Theoretical model

The study examines the inverse U-shaped natural resource rents and economic complexity relationship. When economies are simpler, primary goods production relies on natural resources for income and exports. Natural resource-rich economies may export and generate unprocessed natural resources. This process generates high revenue without a complex economy. Such economies depend on oil, minerals, and agriculture. Thus, economic complexity and natural resources may be negative or weakly correlated (Ahmed et al., 2020; Hussain et al., 2020) but resource extraction rents may rise.

Economic complexity may also boost resource efficiency. Complex economies use advanced technologies, knowledge, and infrastructure to efficiently use natural resources. Advanced manufacturing may improve resource productivity, waste reduction, and utilisation. Complex economies may invest more in research and development(R&D) to develop more sustainable technologies like waste management, recycling, and renewable energy. These methods reduce resource extraction's environmental impact (Miao et al., 2017; Wu et al., 2020). Complex economies affect natural resource extraction and use. Due to diverse industrial practises, economic complexity may increase natural resource demand and production. Complex economies may require more timber, fossil fuels, minerals, and water. Natural resource extraction destroys habitats and depletes resources which can harm biodiversity and ecosystems (Haberl et al., 2020; Xin et al., 2023).

Hence, with the increase in development and complexity of a nation it will look towards a more sustainable source of energy and inputs. The production of complex goods may not require increased natural resources but rather an increase in energy intensity which developed nations could conjure from renewable resources leading to a renewable energy transition (Can and Ahmed, 2023). Doğan et al. (2019) showed that the ECI leads to decreased CO_2 emissions at different stages of development. Therefore the efficiency and substitution of energy effect

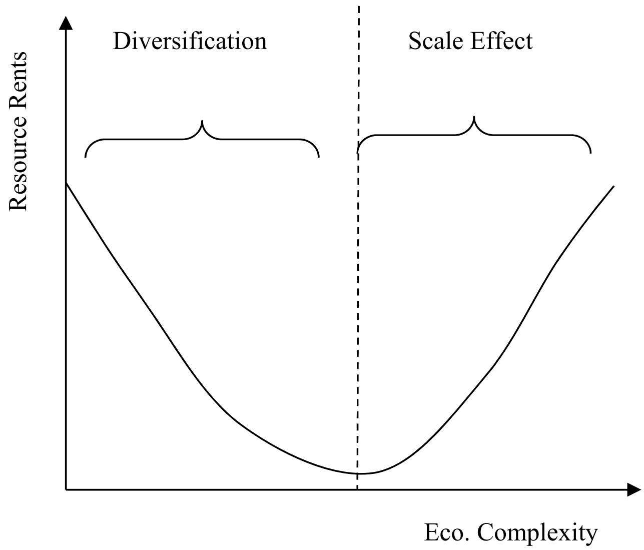

Fig. 2. U-shaped economic complexity and resource rents relationship.

would lead to a fall in the utilisation of natural resources and their rents. This complexity leads to a gradual substitution of natural resources with renewable resources, forming an environmental Kuznets curve (EKC) as shown in Fig. 1.

Literature has also discussed the U-shaped implications of economic complexity and resource extraction. The load capacity curve (LCC) advocates that an increased complexity may start from resource diversification and eventually lead to a scale effect causing higher demand for natural resources as shown in Fig. 2. Guloglu et al. (2023) confirmed that increased income has a U-shaped effect on the environment under LCC in 26 OECD countries.

An economy's production capacity may affect natural resource abstraction. Higher production may increase economic activity and demand for natural resources to support production. Manufacturing requires water, fossil fuel, and energy which increases natural resource use and extraction. Overexploitation, depletion, or environmental degradation may result from resource rate and scale (Ahmed et al., 2020; Ni et al., 2022; Shao and Razzaq, 2022). Green technologies emphasize resource efficiency to maximise natural resource use in consumption and production. Smart grid systems, LED lighting, and energy management systems reduce energy use and improve resource utilisation. Green building technologies and energy-efficient insulation reduce energy use and resource use in operation and construction (Rosen, 2013; Sonnenschein and Mundaca, 2016; Miao et al., 2017).

Delaying renewable energy and sustainability investments in economies with high budget deficits may also reduce renewable energy infrastructure and other sustainable practises. Governments may prioritise budgetary concerns over long-term environmental goals and cut renewable energy research, development, and incentives. This can slow the switch to renewable energy, increase fossil fuel use, and worsen climate change, affecting air, water, and land (Wilde, 2016). As more people need food, water, energy, and other resources, resource consumption increases with population density. This can increase demand for land for agriculture, water for drinking and irrigation, forests for timber, and minerals for infrastructure and manufacturing. Thus, natural resources can deplete, causing over-extraction, deforestation, water scarcity, and other environmental degradation (Molotoks et al., 2018; Maja and Ayano, 2021).

4. Data description and methodology

This study explores countries with natural resource abundance. With the world's largest gas reserves, the US has large reserves of natural gas and crude oil. It mines large amounts of coal, copper, gold, and other minerals And its forests produce timber and paper. Russia has the largest supply of nickel and palladium and has large reserves of diamonds, gold, iron, and other minerals along with oil, natural gas, forests, and fish. Brazil produces soybeans, coffee, sugar, and other crops (Human Development Report, 2019). Many countries have relied on natural resources for trade, investment, and industry. Several economies face natural resource issues. Resource depletion causes shortages and economic instability in resource-dependent nations. Overexploitation can cause air and water pollution, habitat destruction, and biodiversity loss. Due to these environmental impacts, local communities and ecosystems may lose clean water, food, and air (Ivanova et al., 2017; Balsalobre-Lorente et al., 2018).

Table 1
Variable names and data sources.

Symbol	Variable name	Definition	Source
lfr	Forest rents	Difference in the value of harvested wood at regional prices and its regional cost of harvesting (% of GDP)	WDI
ln *gr*	Natural gas rents	Difference of value of produced gas at world prices and its cost of production (% of GDP)	WDI
lcr	Coal rents	Difference of value of produced coal at world prices and its cost of production (% of GDP)	WDI
lor	Oil rents	Difference of value of produced oil at world prices and its cost of production (% of GDP)	WDI
lmr	Mineral rents	Difference of value of produced stock of minerals at world prices and its cost of production (% of GDP). The minerals included in calculation are tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite and phosphate	WDI
lec	Economic complexity	The degree of which the export basket of the country is diversified and complex	Observatory of Economic Complexity
lbd	Budget deficit	Tax revenue – government expenditures (% of GDP)	WDI
lpci	Productive capacity index	Index summarizing the sate of productive capacities in economies worldwide (0–100 index)	UNCTAD Stat
lpd	Population density	People per unit area	WDI
lg *t*	Green technologies	Public investment in developing renewable energy or increasing efficiency of nonrenewable energy	International Renewable Energy Agency

The existing model of several studies such as (Waheed et al., 2018; Farooq et al., 2018; Canh et al., 2020) is protracted in analyzing the association between natural resources, economic complexity, production capacity index, green technology, population density, and budget deficit among several economies bearing excess amount of natural resources. The protracted model is explained as follows:

$$nr = f\left(ec, ec^2, pci, gt, pd, bd\right) \quad (1)$$

nr represents five different types of natural resource rents such as forest, natural gas, coal, oil, and minerals rents at a disaggregated level. However, $ec, ec^2, pci, gt, pd, bd$ denote economic complexity index, its square, production capacity index, green technology, population density, and budget deficit. The detailed descriptions of variables are discussed in Table 1. Further, since the literature has discussed both positive and negative effects of economic complexity, Haans et al.

Table 2
Descriptive statistics.

Variables	Mean	Std. Dev.	Skewness	Kurtosis
lfr	0.285	0.469	3.990	30.449
ln *gr*	0.703	1.148	3.014	14.892
lcr	0.460	0.953	3.703	21.499
lor	13.514	17.413	1.390	4.165
lmr	0.512	0.929	3.573	22.579
lec	0.293	0.815	−0.287	3.487
lbd	0.895	8.771	−0.325	2.339
lpci	55.159	8.142	0.478	2.488
lg *t*	11.159	10.578	2.462	12.712
lpd	64.639	85.014	2.032	7.478

(2016) advocate using a curvilinear function to allow for a transition from positive to negative effects to form an inverted U shape or vice versa for U shape. Taking account of linear specification, the current study has converted all given variables into logarithmic form to ensure more efficient and robust estimates (Shahbaz and Lean, 2012; Sarwar et al., 2017). The converted equation of the function in Equation (1) can be discussed as follows.

$$lfr = \beta_0 + \beta_1 lec + \beta_2 lec^2 + \beta_3 lpci + \beta_4 \lg t + \beta_5 lpd + \beta_6 lbd + u_t \quad (2)$$

$$\ln gr = \beta_0 + \beta_1 lec + \beta_2 lec^2 + \beta_3 lpci + \beta_4 \lg t + \beta_5 lpd + \beta_6 lbd + u_t \quad (3)$$

$$lcr = \beta_0 + \beta_1 lec + \beta_2 lec^2 + \beta_3 lpci + \beta_4 \lg t + \beta_5 lpd + \beta_6 lbd + u_t \quad (4)$$

$$lor = \beta_0 + \beta_1 lec + \beta_2 lec^2 + \beta_3 lpci + \beta_4 \lg t + \beta_5 lpd + \beta_6 lbd + u_t \quad (5)$$

$$lmr = \beta_0 + \beta_1 lec + \beta_2 lec^2 + \beta_3 lpci + \beta_4 \lg t + \beta_5 lpd + \beta_6 lbd + u_t \quad (6)$$

The results are estimated using panel quantile regression and the coefficients shown are based on the median, thus making model estimates robust to outliers and not normal data distribution. The contemporary mean-based models would only provide estimates at mean-center which would not be suitable for inference when the data is not normal. This quantile-based regression can then provide estimates at any location in the distribution of the dependent variable.

Further, if the year count per country is nearing 19 then panel unit root tests can distinguish non-stationary variables from stationary variables which allows authors to use dynamic panel data models for non-stationary variables (Arshed et al., 2018). A two-step ECM was not estimated since panel quantile regression does not store the residuals in STATA. Rather, the short run estimates are generated using one-step ECM forming dynamic fixed effect specification (Blackburne III et al., 2007). For example, Arshed et al. (2022) have used this model to estimate the quadratic impact of debt on poverty.

Table 3
Correlation matrix.

	lfr	ln *gr*	*lcr*	*lor*	*lmr*	*lec*	*lbd*	*lpci*	lg *t*	*lpd*
lfr	1.00									
ln *gr*	−0.07	1.00								
lcr	0.46	−0.21	1.00							
lor	−0.44	0.25	−0.33	1.00						
lmr	0.19	−0.15	0.58	−0.27	1.00					
lec	−0.3	−0.27	−0.08	−0.52	−0.16	1.00				
lbd	0.42	0.16	0.46	−0.54	0.45	0.05	1.00			
lpci	−0.11	−0.15	0.33	0.48	0.33	−0.45	−0.13	1.00		
lg *t*	−0.17	0.05	−0.17	0.28	−0.15	0.04	−0.07	0.11	1.00	
lpd	−0.01	−0.20	0.05	−0.09	−0.17	0.14	0.004	−0.05	0.13	1.00

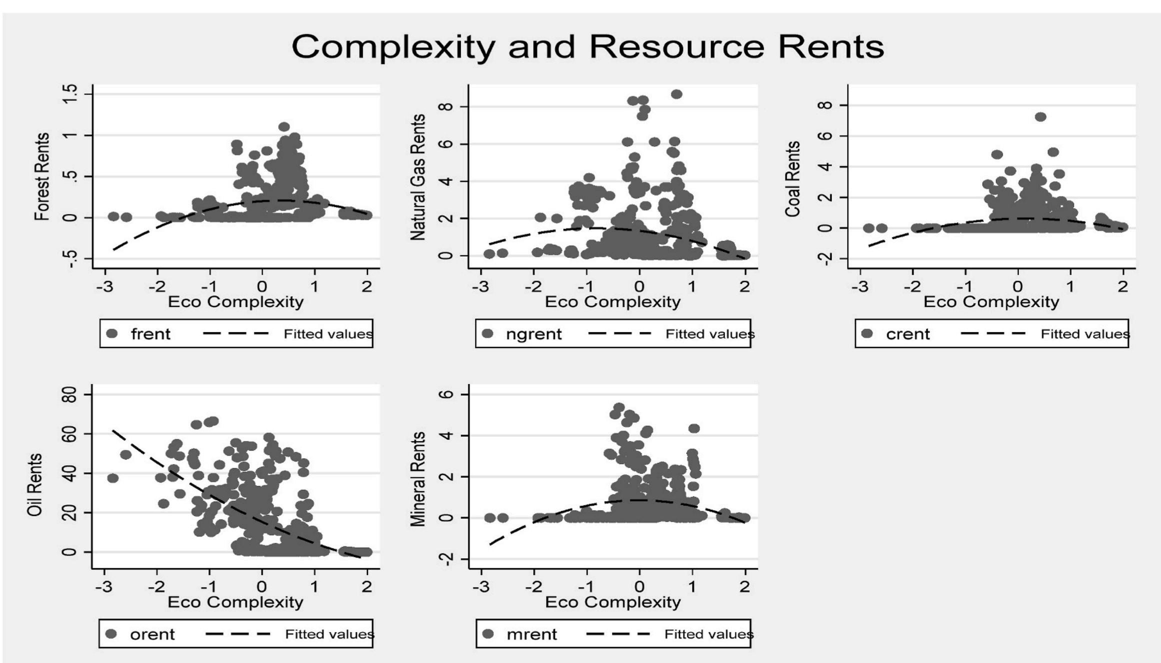

Fig. 3. Association and curvilinear fit of economic complexity and resource rents.

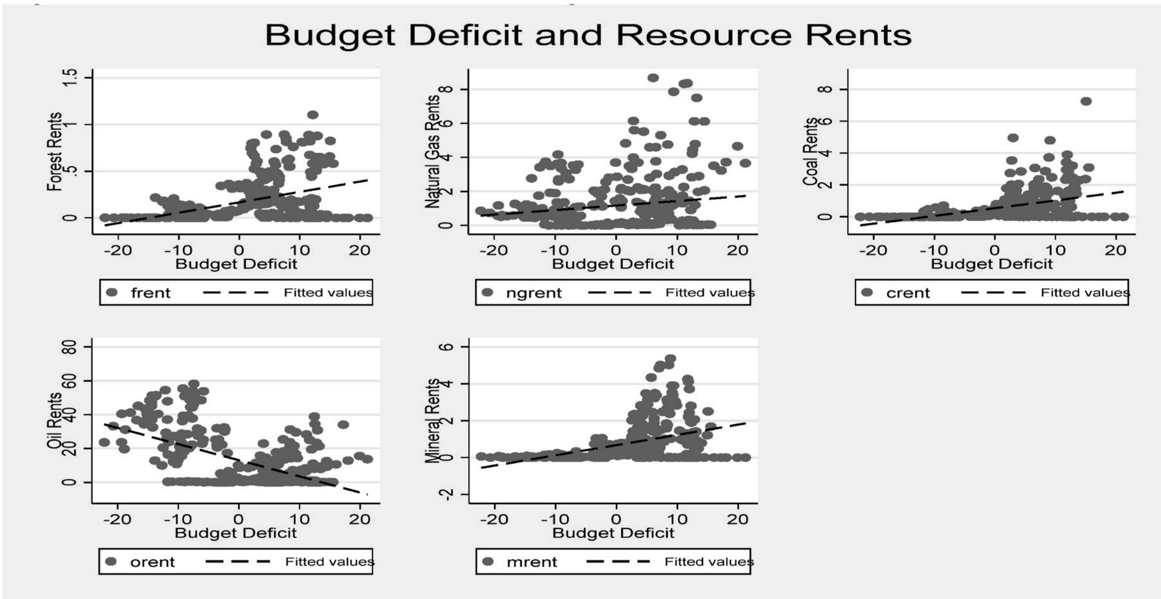

Fig. 4. Association and linear fit of budget deficit and resource rents.

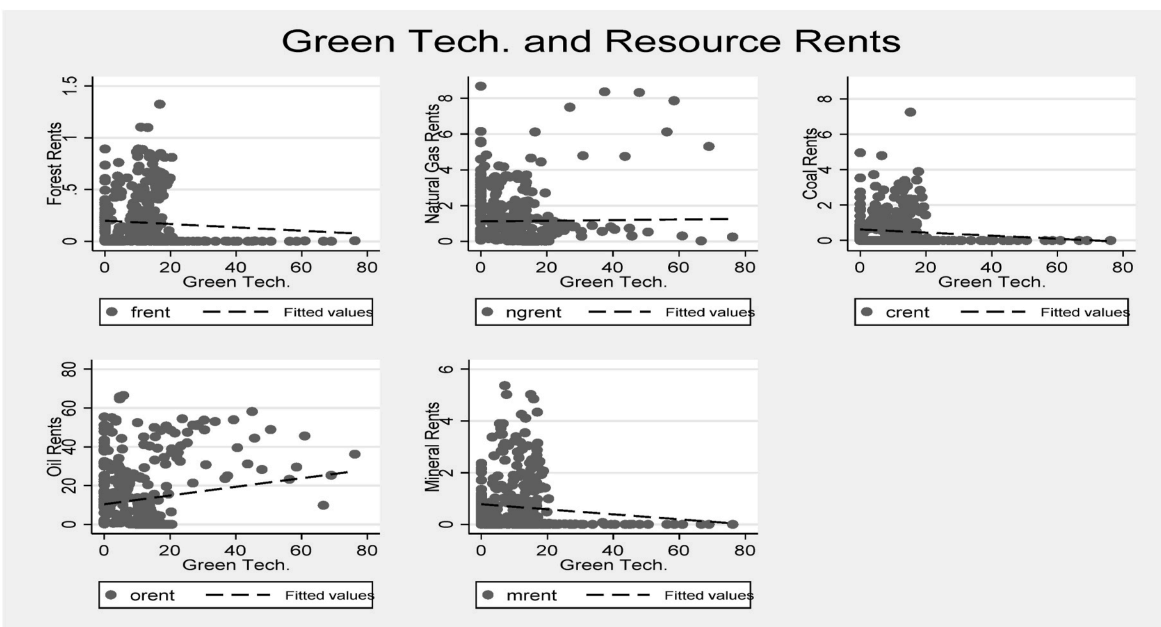

Fig. 5. Association and linear fit of green tech. And resource rents.

5. Results and interpretation

Below. Table 2 provides descriptive statistics where only PCI's mean value is higher than its standard deviation confirming that it is an underdispersed variable while others are overdispersed variables. Further skewness and kurtosis values conclude that most variables are not normal, ruling out mean-based inference models used in literature like panel ARDL or PMG.

Table 3 displays the correlation between the chosen variables; the dependent variable's relationship to the other variables is shown in the first four columns and rows. Although it can be seen that none of the pairwise correlations between the independent variables are exceptionally high, this eliminates the possibility of multicollinearity among the variables (Gujarati, 2022).

Fig. 3 displays a scatter plot of resource rents and ECI with a curved fit. In contrast to other resource rents having a U-shaped association, complexity has an inverted U-shaped association with oil rents. These heterogeneous associations against rents motivated the study to explore the effects of ECI across each resource rent type. Budget deficits are positively correlated with other rents and negatively correlated with oil rents (Fig. 4). This demonstrates how nations face raised rents to cover budget deficits due to extracting resources.

According to Fig. 5, green technology has an inverse relationship with mineral, coal, and forest rents, no relationship with natural gas rents, and a direct relationship with oil rents. Regarding the production capacity (Fig. 6), its rise is connected positively with coal, oil, and mineral rents while adversely with forest and natural gas rents.

The long-run model estimates shown in Equation (1) are presented in

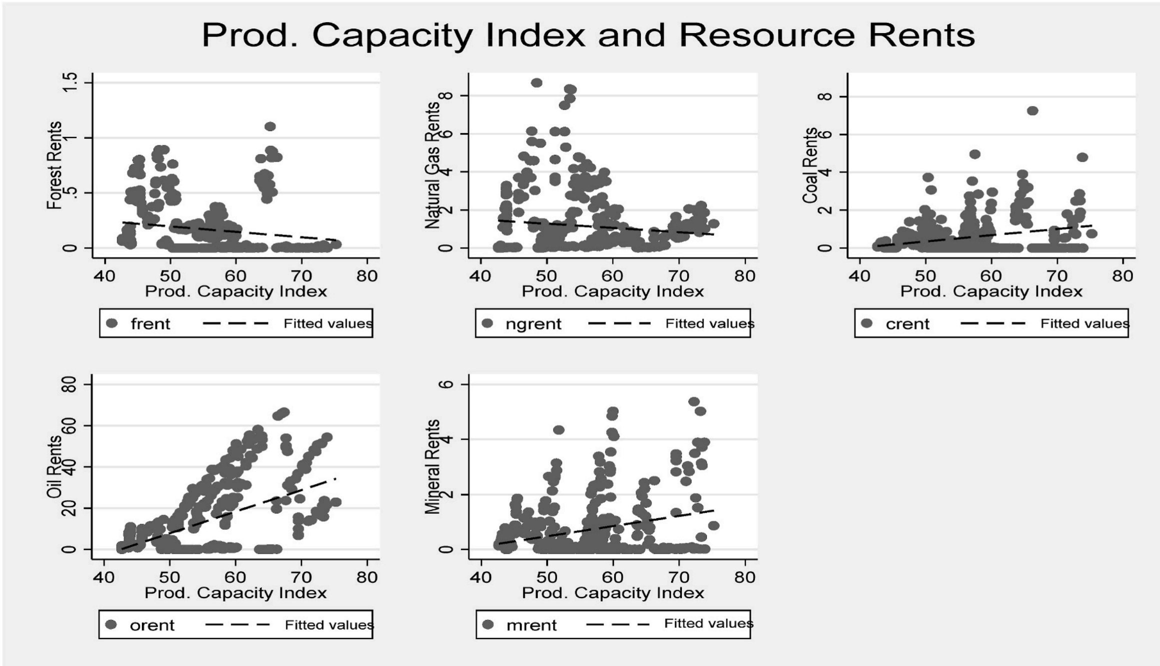

Fig. 6. Association and linear fit of production capacity index and resource rents.

Table 4
Long run panel quantile regression estimates.

Dependent Variables	*lfr*	ln *gr*	*lcr*	*lor*	*lmr*
Independent Variables	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).
lec	−0.008	−0.612	−0.123	−5.345	−0.155
	(0.07)	(0.00)	(0.00)	(0.00)	(0.01)
lec^2	−0.017	0.403	−0.096	1.741	−0.073
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
lpd	0.0002	−0.002	0.0003	−0.009	0.001
	(0.04)	(0.00)	(0.00)	(0.00)	(0.05)
lbd	0.005	0.003	0.031	−0.693	0.033
	(0.00)	(0.31)	(0.00)	(0.00)	(0.00)
lg *t*	−0.002	−0.002	−0.005	0.191	−0.008
	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)
lpci	−0.004	−0.005	0.026	0.502	0.007
	(0.00)	(0.55)	(0.00)	(0.00)	(0.21)
Regression Statistics					
Sample	341	341	341	341	341
Countries	20	20	20	20	20

Table 4. The resource rent types are displayed column-wise. These analyses are based on the top 20 resource-rich nations worldwide. Here, budget deficits are increased by 1% which, in turn, increases forest, natural gas, coal, and mineral resource rents by 0.005%, 0.003%, 0.031%, and 0.033% respectively while having a lowering effect of 0.693% on oil rents. Generally speaking, resource-rich countries rely on resource extraction to pay for their budget deficits which affects the cost of resource extraction (Daniel et al., 2013).

A green technology increase of 1% results in reductions of 0.002%, 0.002%, 0.005%, and 0.008% in the coal, minerals, forests, and natural gas rents respectively. However, it increases oil rents by 0.191 percent. Investments in efficient fossil fuel use can cut down on the need for resource extraction and the associated costs (IEA, 2023).

Forest and natural gas rents are decreased by the country's productive capacity by 0.004 and 0.005 percent respectively while coal and oil rents are increased by 0.026 and 0.502 percent respectively. Productivity in national resource use can have an impact on both scale and efficiency. It might increase demand or lessen the need for further resource exploitation (OECD, 2015).

Population density raises the rents for forests, coal, and minerals by 0.0002%, 0.0003%, and 0.001% respectively while lowering the rents for natural gas and oil by 0.002% and 0.009% respectively. These results comply directly with the empirical outcomes of Repetto and Holmes (1983) and Maja and Ayano (2021).

Since ECI is introduced in quadratic form, it is impossible to determine the curvature of the effects solely from the coefficients because this indicator can have negative values. This study used the ECI range (lowest to maximum) and the coefficients to visualize the quadratic function. Both the linear and squared coefficients are negative against forest, coal, and mineral rents, demonstrating that as ECI rises these rents typically decline exponentially. In this case, an increase in ECI would reduce these resource rents at the median. However, the level coefficient is negative and the squared coefficient is positive against the rents for gas and oil indicating that an increase in ECI tends to affect these rents in a U-shaped manner. This indicates that the ECI follows the LCC theory against resource rents at the median.

Fig. 7 illustrates the actual curve of the relationship between the ECI and resource rents. It shows that forest rents(Fig. 7a) tend to increase as the ECI increases from −3 to 0 but it tends to decrease beyond that point. The ECI exhibits a similar U-shaped effect with a negative effect from −3 to 1 and a positive effect above 1. Therefore, while there is a positive effect it is still below the intercept point in the case of the highest complexity values. The observable result for coal rents(Fig. 7b) is comparable to that for forest rents with the exception that the detrimental effect is more pronounced as a result of economic complexity. The obvious result in the case of oil rents(Fig. 7d) is comparable to that of natural gas rentals(Fig. 7c) with a noticeably less positive reaction to changes in economic complexity for oil rents. The case of the curvilinear influence of ECI on mineral rents is the last(Fig. 7e) with results resembling those of coal and forest rents.

Finally, it should be noted that for the 20 resource-rich countries, an increase in the ECI tends to cause a decrease in resource rents. For indices of disaggregated resource rent it is the passage that varies whereas with regard to forest, coal, and mineral rents, the rents would initially increase and then start to decrease, especially when ECI moves

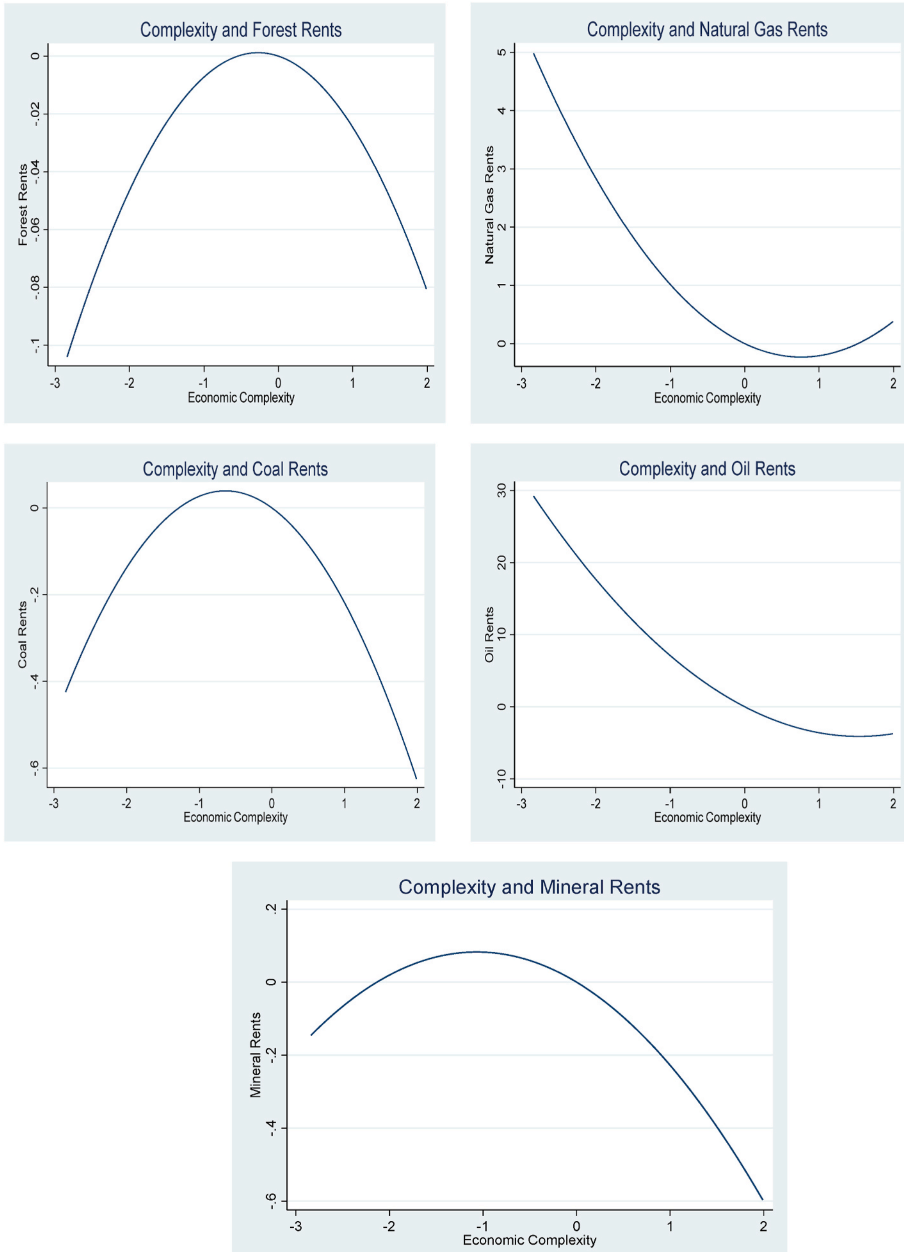

Fig. 7. Quadratic Fit of Complexity and five types of rents.

from negative to positive. The fall in rents corresponding to the ECI, in this case, is more stable for gas and oil rents.

Table 5 shows panel quantile regression short-run estimates. This table tests long-run model cointegration and convergence. ECM_{-1} should be negative with a coefficient between −1 and 0. These five models have negative and significant ECM_{-1} values confirming that the long-run relation is not spurious and can be used for resource policy development. Finally, in quantile-based estimation, resource rents change in the short run due to significant independent variables.

Table 6 provides the quantile-wise long run estimates for each model. Here each row represents the different quantile value of the dependent variable and the numbers in front of it show the effect of the independent variable on the dependent within the specified quantile. This table has provided four different quantile positions, 20%, 40%, 60%, and 80% indicating how the estimates change with the dependent variable location change in the distribution. This is a continuous way to split the data into the low and high dependent variable incidence and compare the marginal effects of selected independent variables. The patterns identified in this table are shown in Figs. 8–12. The changing in the coefficients across percentiles denotes that standard mean based model would have been over-restricted with the assumption that coefficients are homogenous across the distribution.

Fig. 8 above presents the marginal effects against the forest rent at its different quantiles. Here the negative effect of resource capacity on forest rents increases with an increase in quantiles. The positive effect of budget deficit on forest rents increases with an increase in quantiles. Population density and green tech show inverted U-shaped and U-shaped effects on forest rents respectively. With regard to complexity and its squared, it has an inverted U-shaped and increasing negative effects pattern. However, Fig. 9 (above) presents the marginal effects of variables on the natural gas rent at different quantiles. Here the negative effect of resource capacity and green tech on natural gas rents increases with an increase in quantiles. The positive effect of budget deficit and population density on natural gas rents rises with an increase in

Table 5
Short Run ECM based Panel Quantile Regression Estimates.

	Δlfr	$\Delta lngr$	Δlcr	Δlor	Δlmr
	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).	Coef. (Prob).
Δlec	−0.001 (0.00)	0.038 (0.00)	−0.022 (0.00)	−0.738 (0.00)	0.003 (0.08)
Δlec^2	−0.0002 (0.00)	0.038 (0.00)	−0.006 (0.00)	0.069 (0.18)	−0.006 (0.00)
Δlpd	−0.0001 (0.00)	0.009 (0.00)	−0.002 (0.00)	−0.044 (0.00)	−0.002 (0.00)
Δlbd	−0.0001 (0.00)	−0.006 (0.00)	0.001 (0.00)	0.191 (0.00)	0.001 (0.00)
$\Delta \lg t$	0.00002 (0.00)	0.001 (0.00)	−0.000001 (0.96)	0.077 (0.00)	−0.0001 (0.00)
$\Delta lpci$	−0.00001 (0.00)	0.013 (0.00)	0.003 (0.00)	3.332 (0.00)	0.005 (0.00)
Δecm_{t-1}	−0.032 (0.00)	−0.052 (0.00)	−0.212 (0.00)	−0.016 (0.00)	−0.059 (0.00)
lec_{t-1}	−0.00001 (0.19)	0.002 (0.00)	−0.001 (0.01)	−0.049 (0.00)	0.0004 (0.43)
lec^2_{t-1}	−0.0001 (0.00)	0.004 (0.00)	−0.0003 (0.31)	−0.049 (0.00)	−0.003 (0.00)
lpd_{t-1}	−0.000001 (0.00)	−0.0001 (0.00)	0.0001 (0.00)	0.0001 (0.00)	0.00005 (0.00)
lbd_{t-1}	0.00001 (0.00)	0.0003 (0.00)	0.002 (0.00)	0.004 (0.00)	0.001 (0.00)
$\lg t_{t-1}$	0.0000 (0.00)	−0.0002 (0.00)	−0.0003 (0.00)	0.019 (0.00)	−0.0004 (0.00)
$lpci_{t-1}$	−0.0001 (0.00)	0.0006 (0.00)	0.002 (0.00)	0.008 (0.00)	0.002 (0.00)
Regression Statistics					
n	341	341	341	341	341
Countries	20	20	20	20	20

quantiles. in respect of complexity and its square, it has increased negative effects pattern and inverted U-shape respectively. Similarly, Fig. 10 presents the marginal effects of variables on the coal rent at its different quantiles. Here is the inverted U-shaped effect of population density and green tech on coal rents. The positive effect of the budget deficit and resource capacity on coal rents increases with an increase in quantiles. With regard to complexity and its square it has a U-shaped and increasing positive effects pattern respectively.

Fig. 11 presents the marginal effects of variables on the oil rent at its different quantiles. Here is the inverted U-shaped effect of the resource capacity budget deficit on oil rents. The positive effect of green tech on oil rents increases with an increase in quantiles. Population density shows a U-shaped effect on oil rents. For the case of complexity and its square, it has increased negative effects pattern and inverted U shape respectively. Fig. 12 below presents the marginal effects of variables on the mineral rent at its different quantiles. The positive effect of green tech, budget deficit, and resource capacity on mineral rents increases with an increase in quantiles. Population density shows an increase in a negative effect on mineral rents. With regard to complexity and its square, it has increasing positive effects pattern and U shape respectively. This outcome of the panel quantile ARDL model helps policymakers define specific policies for their country based on the quantile position of their resource rents while staying within the generalization of overall effects.

After discussing the pattern of long run effects across distribution, this study explores the changes in the quadratic effect of economic complexity on the several types of resource rents in Fig. 13. In Fig. 13a, while aligning countries in terms of increase in forest rents percentiles, the quadratic curves change from U-shaped to inverted U-shaped. This shows that low forest rent countries follow LCC while high forest rent countries follow EKC. In Fig. 13b, with a percentile-wise increase in natural gas rents, the curve changes from negative dominating U shaped to invert U-shaped. This depicts the transition from LCC to EKC hypothesis when comparing low and high natural gas rent countries.

In Fig. 13c, the curve changes from an inverted U-shaped to U-shaped with an increase in coal rents. Countries aligned in terms of coal rent percentile transition from EKC to LCC hypothesis. In Fig. 13d, the negative slope curve becomes steeper with increased oil rents percentiles. This indicates towards steepening of the EKC hypothesis. In Fig. 13e, the curve changes from a negative slope to a positive dominating inverted U shape with an increase in mineral rents. This outcome indicates the flattening of the EKC hypothesis.

5.1. Discussion

ECI negatively and significantly affects forest, natural gas, coal, oil, and mineral rents. Estimates match with Danish et al. (2019) and Dong et al. (2019). Economic complexity decreases natural resource rents by upgrading production processes. This may reduce an economy's

Table 6
Quantile-wise estimates of long run models.

Variables	lec	lec^2	lpd	lbd	$\lg t$	$lpci$
Percentiles	Forest Rents Model					
20	0.006	0.005	−0.0001	0.0004	−0.0002	−0.0008
40	0.039	−0.034	0.0001	0.0039	−0.0017	−0.0006
60	0.001	−0.032	0.0002	0.0045	−0.0023	−0.0017
80	−0.014	−0.031	−0.0002	0.0171	0.0002	−0.0022
Percentiles	Natural Gas Rents Model					
20	−0.251	0.037	−0.0004	−0.0138	−0.0064	0.0027
40	−0.605	0.250	−0.0010	−0.0077	−0.0002	−0.0109
60	−0.536	0.363	−0.0013	0.0122	0.0099	0.0058
80	−0.710	−0.110	−0.0055	0.0348	0.0511	−0.0579
Percentiles	Coal Rents Model					
20	0.0066	−0.0822	0.0013	0.0094	−0.0095	0.0081
40	0.0373	−0.0851	0.0011	0.0230	−0.0091	0.0253
60	−0.0984	−0.0155	0.0017	0.0287	−0.0072	0.0209
80	0.0322	0.0584	0.0011	0.0517	−0.0114	0.0376
Percentiles	Oil Rents Model					
20	−2.2729	−0.6023	−0.0071	−0.8276	0.0795	0.0515
40	−1.6462	0.7918	−0.0323	−0.7780	0.0996	0.9692
60	−3.7731	2.6933	−0.0369	0.1552	0.1406	1.6902
80	−6.2856	−0.1648	−0.0294	−0.3515	0.2859	−0.1304
Percentiles	Mineral Rents Model					
20	−0.1069	−0.0181	0.0003	0.0111	−0.0054	−0.0027
40	0.0823	−0.1159	−0.0004	0.0160	−0.0040	0.0005
60	−0.0149	−0.1038	−0.0012	0.05331	−0.0043	0.0325
80	0.1503	−0.0539	−0.0015	0.0529	−0.0072	0.0472

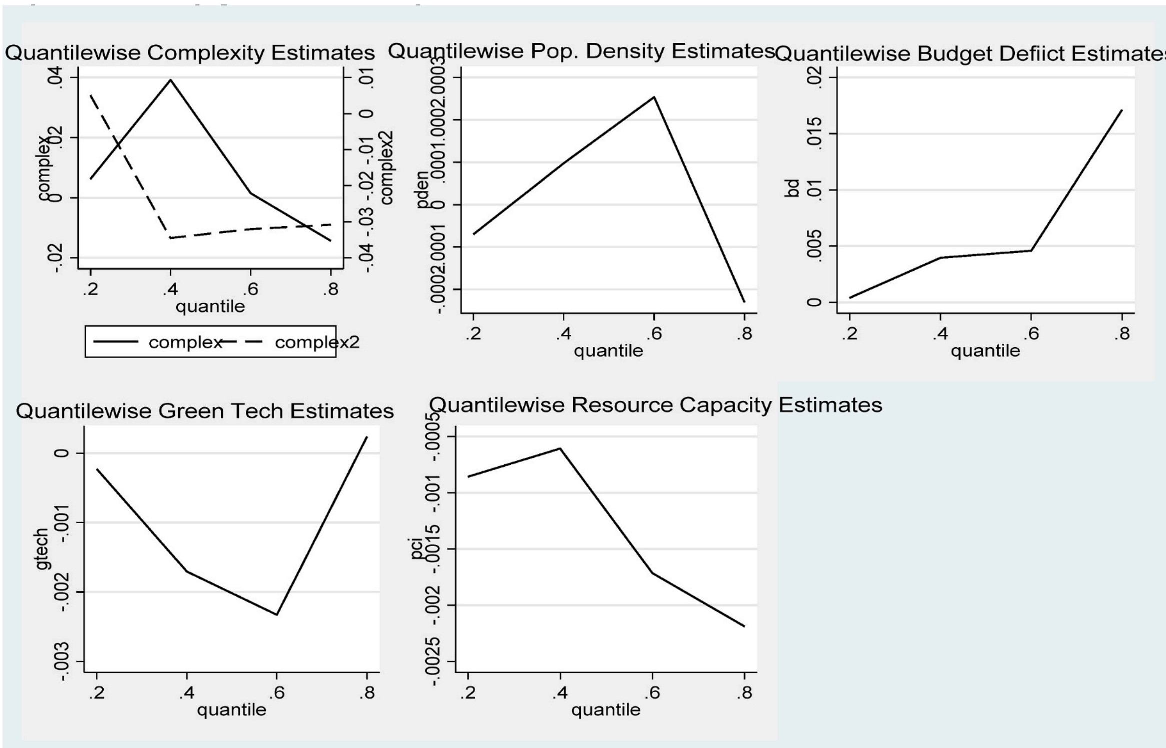

Fig. 8. Plotting quantile-wise long run estimates in forest rent model.

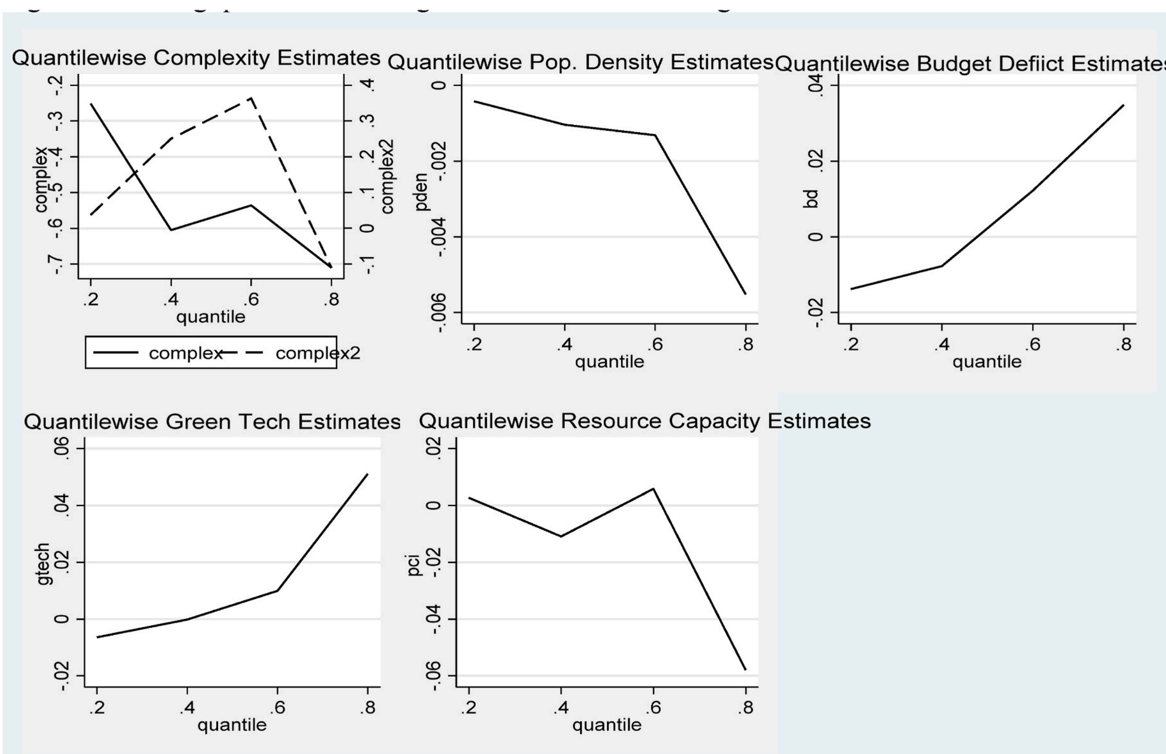

Fig. 9. Plotting quantile-wise long run estimates in natural gas rent model.

dependence on raw materials and increase its exports of value-added goods. New technology diversifies production and reduces natural resource extraction in complex economies (Zhang and Brouwer, 2019). Market concentration can also result from economic complexity. This may limit forest owners' bargaining power and competition, lowering forest prices and rents. Market concentration may cause dominant entities to exploit forest resources to maximise profits, lowering forest rents (Canh et al., 2020). This study iterates the relevancy of ECI in

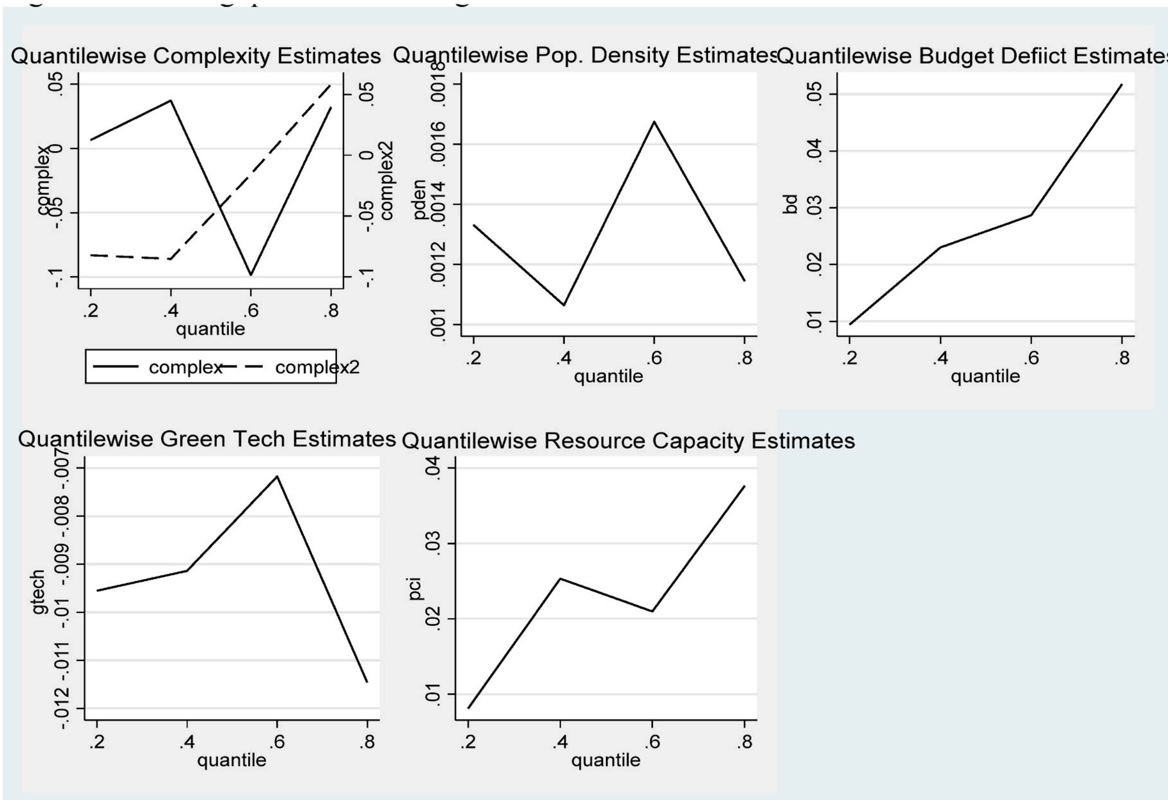

Fig. 10. Plotting quantile-wise long run estimates in coal rent model.

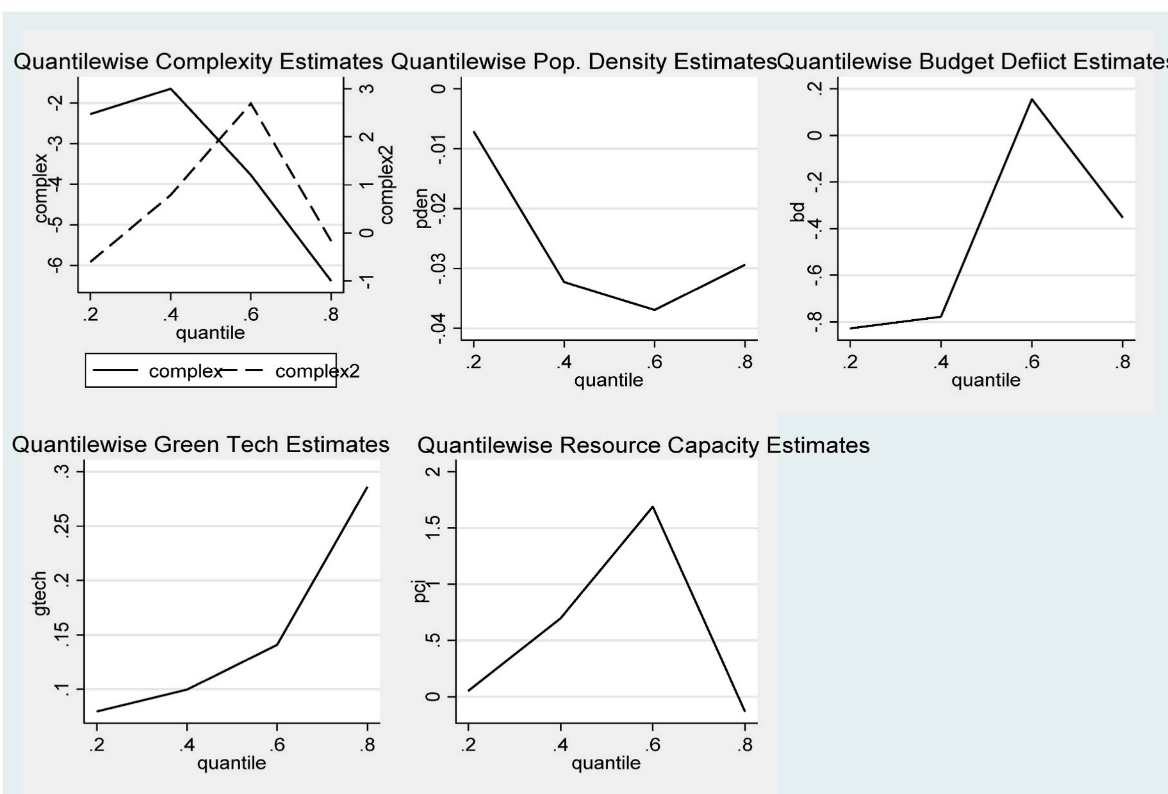

Fig. 11. Plotting quantile-wise long run estimates in oil rent model.

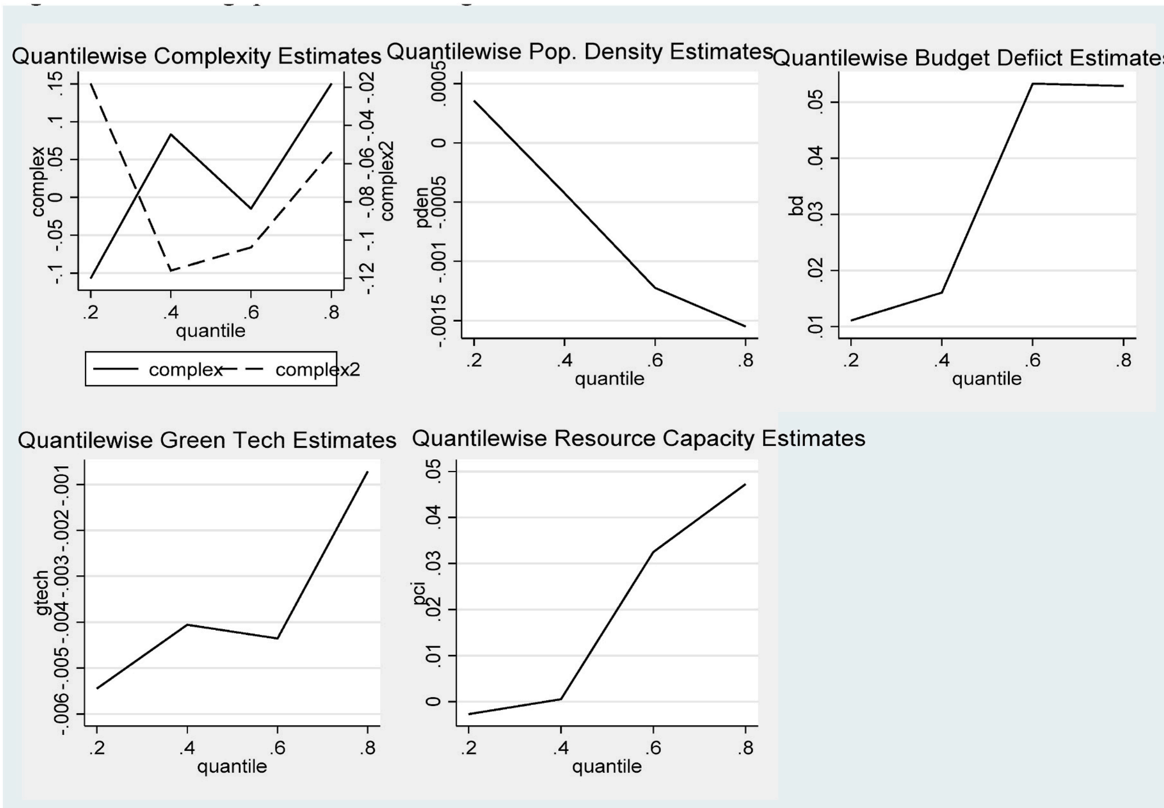

Fig. 12. Plotting quantile-wise long run estimates in mineral rent model.

managing natural resource rents.

Due to a focus on knowledge and innovation-based industries and value-added services, advanced economies diversify and become more complex. At this stage, economic complexity and natural resources become negative because the economy relies less on natural resources and more on knowledge and innovative activities. The economy may invest more in knowledgeable and sustainable technologies to reduce natural resource consumption and environmental impacts. Due to factors like technological capabilities, resource endowment, global market dynamics, and policy framework, the inverse U-shaped relationship between economic complexity and natural resources may vary across economies. Economic complexity and natural resources may be positive or negative depending on resource management. Sustainable resource management, environmental regulations, and decoupling economic growth from resource consumption can balance economic complexity and natural resources for sustainable development (Chopra et al., 2022; Rafei et al., 2022).

According to empirical estimates, production capacity increases oil and coal rent and decreases forest rent. Production capacity affects resource efficiency. Technology, economies of scale, and well-organized processes can optimise resource utilisation and reduce waste with higher production capacity. Resource efficiency can reduce production's impact on natural resources and promote sustainable resource management. Production capacity affects resource diversification and substitution. Based on technological advancement, availability, and cost, an economy's production capacity may switch natural resources. Diversifying production capacity across sectors and industries can reduce risks of resource dependence and price volatility (Abumunshar et al., 2020; Sadeghi et al., 2020). This outcome points to regulation to subsidize renewable energy use to minimize the scale effect.

Current study estimates show a negative and significant relationship between green technology and all resource rents. Green technology may reduce oil resource rents in resource-rich economies. Evidence supported by Can and Gozgor (2017), Doğan et al. (2019) and Lee and Chen (2021). Green technology can replace non-renewable energy with renewable energy, reducing environmental damage. Bioplastics can replace fossil fuels consequently reducing resource pressure and promoting environmental sustainability (Rosen, 2013; Sonnenschein and Mundaca, 2016; Miao et al., 2017). Some green technologies restore polluted or degraded natural resources. Soil remediation, water purification, and air pollution control can improve natural resources. These technologies can restore and sustain natural resources. Green technologies help people reduce their ecological footprint, support sustainable resource management, and fund the conservation and sustainable use of natural resources for future generations (Ahmed et al., 2020; Ni et al., 2022; Shao and Razzaq, 2022).

In natural resource-rich economies, budget deficits positively and significantly affect all natural resource rents except oil. The government can use deficit financing to improve the environment, green infrastructure, and sustainable practices as part of economic recovery. Ecosystem restoration, renewable energy, and climate adaptation financing can help restore and protect natural resources and promote sustainable resource management. However, budget deficits may pressure extractive industries like logging, mining, and oil exploration to finance deficits with natural resources. The state may grant more concessions and tax relief to accelerate resource extraction and increase revenue. This may overexploit natural resources and degrade an ecosystem (Molotoks et al., 2018; Maja and Ayano, 2021).

6. Conclusion

The debate on whether natural resources are a blessing or curse for economic development has been ongoing for decades with no clear consensus in the literature. This study contributes to the literature by examining the relationship between resource rent, economic complexity, clean technology, and resource productivity capacity in

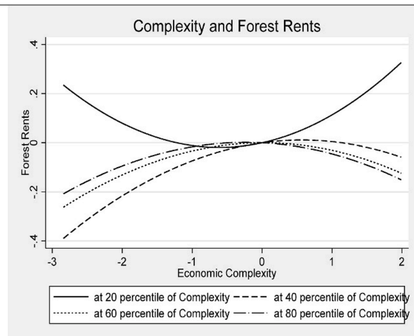

Figure 13a: Quantile-wise quadratic effect economic complexity on forest rents

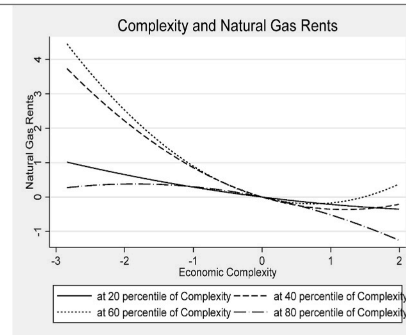

Figure 13b: Quantile-wise quadratic effect economic complexity on natural gas rents

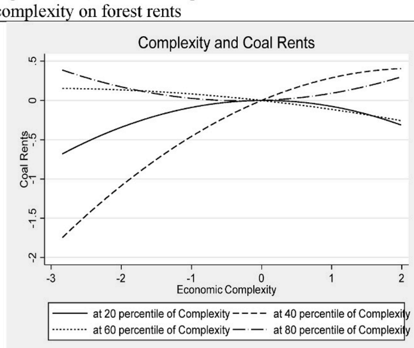

Figure 13c: Quantile-wise quadratic effect economic complexity on coal rents

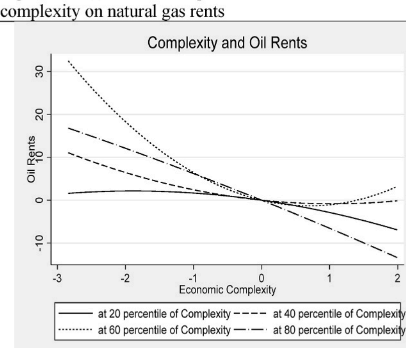

Figure 13d: Quantile-wise quadratic effect economic complexity on oil rents

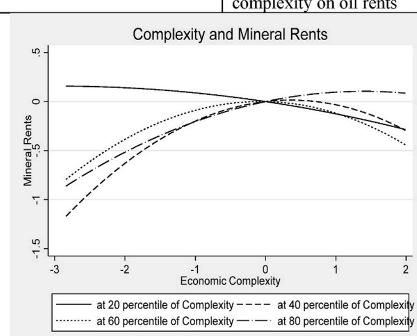

Figure 13e: Quantile-wise quadratic effect economic complexity on mineral rents

Fig. 13. Quantile-wise quadratic effect economic complexity on several types of resource rents.

several resource-rich economies between 2000 and 2021. The study takes a disaggregated approach by examining five different types of natural resource rents, namely coal, oil, minerals, natural gas, and forest rents.

The study's primary contribution to the existing literature is using a quadratic function to elaborate the inverse U-shaped relationship between economic complexity and natural resource rent. Further, by using the quantile-wise effects this study explores the transition from U to inverted U-shaped and vice-versa. The study hypothesizes that an increase in the ECI follows a curvilinear effect on resource extraction, consequently changing resource rents. This curvilinear effect is explained by EKC and LCC hypothesis. The findings of this study have significant implications for policymakers and resource-rich economies seeking to diversify their economies and promote sustainable development. The strategies included in the study are economic complexity, productive capacity, and green technology.

This study has used the panel quantile ARDL approach with dynamic fixed effect specification. The long-run estimates are provided for the median and then plotted for 20, 40, 60, and 80 percentiles to assess the changes in the slope heterogeneously across the distribution. The quadratic effect is initially plotted at the median and followed by the estimated percentiles to see how the quadratic effect changes with changes in the size of the dependent variable. The study found a negative and significant relationship between economic complexity and natural resource rents, with the negative association reflecting upgrading in the production process, which reduces the dependency of an economy on raw and natural resource materials. Additionally, an increase in green technology reduces all types of resource rents except for oil rents.

The study suggests several policy options. There must be efforts to enhance resource efficiency. Policymakers can devise appropriate interventions based on the size of resource rents. Countries must diversify production capacity and promote sustainable resource management practices that can help mitigate the negative impacts of production on natural resources and promote sustainable development. The scale effects of technology and productivity can be sorted by altering the relative costs of different energy options.

The inverse U-shaped association between economic complexity and natural resources is subjective to many indicators such as technological capabilities, resource endowment, global market dynamics, and policy framework. Therefore, sustainable resource management practices, environmental regulations, and efforts to decouple economic growth from resource consumption can help balance economic complexity and natural resources to promote sustainable development.

Ethical approval

The entire research process is in line with our institutional research ethics policy. We declare that all ethical standards are met and complied with in true letter and spirit.

Informed consent

All participants in this study volunteered themselves during the entire research process, and their consent was taken at inception.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author statement

Conceptualization; Shajara Ul-Durar, Noman Arshed[ORCID], Awais Anwar and Arshian Sharif. Data curation; **Shajara Ul-Durar and Noman Arshed, Awais Anwar and Wei Liu.** Formal analysis; **Shajara Ul-Durar, Noman Arshed, Awais Anwar and Wei Liu**. Funding acquisition; **No funding associated**. Investigation; **Shajara Ul-Durar, Noman Arshed and Arshian Sharif**. Methodology; **Shajara Ul-Durar, Noman Arshed and Awais Anwar**. Project administration; Shajara Ul-Durar and Noman Arshed. Supervision; **Shajara Ul-Durar, Arshian Sharif**. Writing - original draft; **Shajara Ul-Durar, Noman Arshed, Awais Anwar and Arshian Sharif.** Writing - review & editing; **Shajara Ul-Durar, Noman Arshed, Awais Anwar, Arshian Sharif and Wei Liu**.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

We confirm that there are no competing interests which can impact ethical integrity of work submitted.

Data availability

No data was used for the research described in the article.

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