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FinTech adoption in achieving ecologically sustainable mineral management in Asian OBOR countries – A cross-section and time autoregressive robust analysis

Shajara Ul-Durar [a,b,*], Marco De Sisto [c], Noman Arshed [d], Shabana Naveed [e], Madiha Rehman Farooqi [f]

[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] School of Management, RMIT University, 445 Swanston Street, Melbourne VIC 3000, Australia
[d] Department of Economics, Division of Management and Administrative Science, University of Education Lahore, Pakistan
[e] Faculty of Management Sciences, University of Central Punjab, Lahore, Pakistan
[f] University of Education, UK

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ABSTRACT

The balance between economic activity, economic growth, and ecosystem is a need of the time. Belt and Road Initiative countries working on the One Belt and One Road project (OBOR), constituting 130 countries, are participating with China to achieve growth via trade. These countries, where trade and commerce have influence, are rich in natural minerals as well as natural habitat and biodiversity. Along with infrastructural efforts, the world is also experiencing a growth in technology 4.0, specifically its gains in terms of financial innovation. This study has explored 27 countries from the Asian OBOR group and assessed the potential moderating role of FinTech on resource extraction sustainability. The results from multi-dimensional, long-term, and robust estimates showed that resource rents harm environmental performance and FinTech positively moderates this relationship. This study is instrumental for the policymakers in quantifying the hampering spillover/spatial effects and diminishing time horizon policy effectiveness.

1. Introduction

The Belt and Road Initiative (BRI) is an infrastructural development strategy to increase connectivity and cooperation among several economic corridors spanning more than 130 countries. The group has far-reaching consequences for the global economy, mineral resources, environmental sustainability, and digital technology adoption. The primary driver, China, has already invested significantly in transportation-related projects in BRI partners including road, rail, aviation, shipping, and logistics (OECD, 2018; World Bank Group, 2019). China has also acquired critical mineral extraction contracts in BRI countries in order to advance industrial advancement in fields such as semiconductors, artificial intelligence, and electric vehicles (Bindman, 2023; SCMP, 2023).

Though BRI has shown promising growth, it has raised concerns about its environmental impact, particularly on biodiversity and natural habitat (CFR, n.d.; Du et al., 2019; Kurlantzick, 2020; Ng et al., 2020; ShareAmerica, 2020). If infrastructure projects are properly implemented, the BRI can significantly attract resources and wealth to South Asia and China (Ali et al., 2022). The BRI countries face challenges in natural resources management to achieve sustainability as they are associated with extensive emissions of by-products, smoke, and materials as a source of environmental degradation (Wu and Madni, 2021). As a result of financial and response capacities heterogeneities BRI countries are vulnerable to invasive species in different ways and these countries overlap with 27 of 35 recognised global biodiversity hotspots (Liu et al., 2019). South Asian countries' economic growth is heavily dependent on the industrial sector so it is critical to developing a CO_2 emissions reduction strategy while reaping the potential benefits of the OBOR project, particularly with regard to increasing industrialisation

* Corresponding author. University of Sunderland, The School of Business Management, Edinburgh Building, Chester Road, Sunderland, SR1 3SD, UK.
E-mail addresses: Shajara.ul-durar@sunderland.ac.uk, Shajara.ul-durar@durham.ac.uk (S. Ul-Durar), marco.desisto@rmit.edu.au (M. De Sisto), noman.arshed@ue.edu.pk (N. Arshed), shabananaveed@ucp.edu.pk (S. Naveed), madiha.rehman@ue.edu.pk (M.R. Farooqi).

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and transportation (Wu and Madni, 2021). Green approaches based on 6 R technologies (rethink, redesign, recovery, recycle, reuse, reduce) and closed-loop systems with industrial ecology offer excellent opportunities to save natural resources (Wu and Madni, 2021).

Reducing the environmental impacts of BRI in Asia is a need as infrastructure development can disturb the local biodiversity (Hughes, 2019). In the landscape of ecological economics, the natural resource management, industrialisation, population density, and environmental sustainability connection demand a nuanced exploration. The results of this investigation reveal the combined impact that these three factors have on environmental performance. In addition, the potential moderating role that Financial Technology (FinTech) could play as a catalyst for the sustainable resources management is investigated.

Natural resource rents as the monetary gains derived from the extraction of Earth's treasures are an essential component in the discussion of environmental economics. The resource curse hypothesis (Auty, 1993) posits that nations heavily dependent on natural resource extraction may grapple with economic distortions and environmental degradation. The over-exploitation of resources frequently results in the habitat destruction, deforestation/afforestation, and air pollution which marks them as low environmentally performing countries.

While exploiting natural resources, these economies tend to take the path of industrialisation. With societal progress through the industrialisation stages, a conundrum emerges wherein economic prosperity and environmental well-being are substitutes. The environmental Kuznets curve (Grossman and Krueger, 1995) suggests an inverted U-shaped relationship between income per capita and environmental degradation. In the early stages of industrialisation, environmental stress tends to escalate but, as income levels rises, a turning point is reached leading to a decline in degradation as societies prioritise environmental conservation.

Asian OBOR countries are mostly densely populated which motivated them to be part of infrastructure development projects. Population density introduces a dimension of environmental stress. Higher population density correlates with increased resource consumption and waste generation, intensifying the environmental burden. Hence, population density does come into the equation when exploring the resource exploration and environment link. However, acknowledging the role of technology and innovation becomes paramount in mitigating the environmental impact associated with population density.

Enter FinTech, a technological disruptor in the financial realm, poised to play a pivotal role in moderating the complex relationship between natural resource use and environmental performance (Liu et al., 2024; Murshed, 2024). Blockchain technology, a prominent facet of FinTech, offers unparalleled transparency in supply chains reducing the likelihood of illegal and unsustainable resource extraction (Awais et al., 2023; Ma et al., 2023; Nenavath and Mishra, 2023). Through enhanced financial transparency, resource valuation, and investment in sustainable practices, FinTech emerges as a potential ally in steering societies toward responsible resource management (Taylor, 2023).

Synthesising these theoretical frameworks, a holistic model that integrates the resource curse hypothesis, environmental Kuznets curve, and the moderating influence of FinTech is proposed in this study. The nations may experience ecological distress and environmental degradation during the early industrialisation stages and increased natural resource reliance. The challenge is that as income levels rise, so would the resource extraction demand. This study proposes that, when FinTech interventions are included in this scenario, there is a positive shift toward sustainable resource management. For panel data, this study opts for the heterogenous factor analysis approach to develop the FinTech index. Lastly, while considering the interlinkage of OBOR countries via infrastructure and trade, this study allows the spatial linkage between countries in estimating a dynamic robust model for ecologically sustainable mineral management.

Addressing the policymakers and practitioners who are looking for sustainable resource management, this integrated viewpoint has far-reaching and multipronged implications. The digitisation of economies in order to lessen reliance on natural resource and increase its efficient utilisation, the promotion of responsible industrialisation practises, and the utilisation of FinTech in order to achieve transparency and accountability are absolutely necessary imperatives.

2. Literature review

Empirically, several studies have looked into the resource rents impact on environmental quality. This study delves into the resource extraction impact on biodiversity and ecosystem vitality. Alvarado et al. (2021) provide a novel approach to analysing environmental degradation in Latin American countries that rely heavily on natural resource rents. Quantile regressions are used in the study to investigate the relationship between ecological footprint, economic complexity, and natural resource rents.

A study by Ul-Durar et al. (2023) stated that complex economies tend to use more natural resources which also points toward a necessity for finding sustainable approaches so that economic advancement is not hindered. Erdogan (2023) used a panel data approach based on the load capacity curve hypothesis that connects natural resources and environmental sustainability. He investigated the impact of natural resources on ecological performance and concluded a negative resource rent and environmental performance relationship. A study by Bădîrcea et al. (2023) investigated the natural resource rent, income level, and energy consumption effects on environmental quality in G7 economies to conclude that natural resource rents have a significant impact on environmental performance.

A spatial analysis study by Mahmood et al. (2023) investigated the spatial oil and natural gas rents effects on CO_2 emissions in 17 Middle Eastern and North African economies. According to them, natural resource rents significantly impact CO_2 emissions whereby resource-rich countries may face challenges in managing their environmental footprint. A study by Abbas et al. (2022) investigated the natural resources crowding out effect on domestic investment. According to the study, increasing natural resource rent should increase domestic income, leading to domestic investment and industrialisation. Literature has shown that an increase in economic activity or industrialisation leads to environmental deterioration (Arshed et al., 2021; Wang et al., 2021). Similarly natural resource rents have direct significant impact on environmental performance and environmental degradation (Bădîrcea et al., 2023; Erdogan, 2023).

Natural resource extraction affects environmental performance in many ways which are discussed in literature. Mining of natural resources can lead to biodiversity and habitat destruction, in addition to ecosystems degradation. A major reason behind this is deforestation, the release of pollutants, and soil erosion (MSCI, 2021; Sonter et al., 2018). In the case of wood resource, excessive deforestation leads to habitat loss and ecological imbalance. It can permanently reduce the forest cover, diminish soil nutrients and create hydrological cycle disturbance (Fuwape, 2003).

Oil resource extraction also has serious consequences for biodiversity and ecosystems. This process could lead to oil spills. Furthermore, reliance on oil rents has significant negative environmental and biodiversity consequences (Elmassah and Hassanein, 2022; Fathurrahman and Bakimli, 2021). Though financial innovation improves environmental quality, as discussed in literature, it is critical to consider the specific context and potential trade-offs for OBOR countries. The technological innovation impact on ecological quality in OBOR countries has been studied with research indicating a possible positive technological innovation and environmental performance relationship (Bilal et al., 2022). Several studies have investigated the positive financial inclusion impact on economic-environmental performance in OBOR countries (D. Liu et al., 2022; Tsimisaraka et al., 2023). Green economic growth and environmental sustainability have been linked to FinTech innovation through green investment, lending, and the eco-friendly practices adoption (Guang-Wen and Siddik, 2023).

Financial innovation and FinTech aids in natural resources reliance reduction. It can improve resource extraction efficiency and sustainability (Li et al., 2023). Green and sustainable finance have been linked to environmental protection and sustainability via renewable energy transition and carbon emissions reduction (Ben Belgacem et al., 2023). Conclusively, financial innovation can aid in the environmentally friendly and sustainable resource extraction and utilisation practices transition. An efficient and robust financial system can extend environmental finance to industries and contribute in high energy efficiency promotion, low pollution generation, and green research and development, thereby contributing to improved technological innovation and the low-carbon technologies incorporation for business growth (Ganda, 2022).

There have been many studies that provided a significant effect when population density is linked to an ecosystem. A study examining the socio-economic predictors of ecosystem change and degradation across African nations found that increasing population density and overall economic activity are the most strongly correlated with greater environmental degradation (Bradshaw and Di Minin, 2019). The Californian counties found a moderate negative correlation between population density and transportation emissions and it was observed that higher population density might lead to lower average driving distances and improved air quality (Sterling, 2018).

A review of the relationships between human population density and biodiversity change discovered reasonably good evidence for spatial congruence between people and species-rich regions with available energy and elevation appearing to be key mutual drivers (Luck, 2007). The same review concluded that the evidence for increased human population density as a threat to conservation was weak owing to the extreme heterogeneity of approaches used to address this issue (Luck, 2007).

The industrialisation process has significantly impacted environmental performance with both positive and negative consequences. Industrialisation has led to severe pollution, resource depletion, species extinction, and water pollution (Folk, 2021; Hayes, 2022). Burning fossil fuels and releasing toxins by industries have contributed to air, water, and soil pollution, and habitat destruction (Folk, 2021). Industrialisation is often associated with economic development and improved living standards but it has come at a cost to the environment including increased greenhouse gas emissions, depletion of natural resources, and pollution (Anderson, 2023; Terrapass, 2022).

The Industrial Revolution, which marked the beginning of large-scale industrialisation, significantly altered how energy and manufactured goods were generated and increased environmental pressures (openLearn, n.d.). The environmental impact of industrialisation became more apparent in the decades following the Industrial Revolution with signs of environmental damage, such as air and water pollution, becoming increasingly evident (Hayes, 2022).

This study is instrumental in exploring the potential role of FinTech in improving ecological sustainability in resource extraction. The efficiency of this moderator model assessment is ensured in several ways. This study used Panel Quantile Regression with Dynamic Fixed Effect and Spatial Autoregressive specification to generate efficient estimates using information from cross-sectional and time series autocorrelation and distributional heterogeneity of dependent variables in the Asian OBOR region.

3. Theoretical model

Financial Technology's (FinTech) incorporation into natural resource management can reshape the natural resource rents and environmental performance relationship (Mertzanis, 2023). Sustainable mineral management and FinTech integration represents a transformative leap toward responsible resource utilisation and extraction, aligning with the broader goals of sustainable development. Using blockchain technology, FinTech provides unprecedented supply chain transparency, addressing resource extraction and utilisation traceability challenges. This can help to reduce the illegal and unsustainable resource extraction risks while also increasing stakeholder accountability (Ni et al., 2023). Smart contracts as a part of financial innovation enables the sustainability criteria incorporation into resource-related transactions to align financial interests with environmental stewardship (Ni et al., 2023). The natural assets tokenisation enablement broadens the participation in sustainable resource management initiatives. It helps in funding resource diversification for environmentally responsible practices (Ni et al., 2023). FinTech tools include real-time data analysis on resource extraction and its environmental spillover effects. The aim is to improve the adaptive management strategies and allow for more informed decision-making in balancing economic activity with environmental preservation (Ni et al., 2023). FinTech allows businesses to increase KPIs as targets, social KPIs like environmental, social, and governance (ESG) criteria help make investment decisions socially sustainable and create a market-driven incentive for industries to prioritise environmental concerns (Ni et al., 2023).

In addition, empirical studies excessively discussed that financial technology development like FinTech has the potential to increase efficiency of green innovation to aid in air pollution reduction (Ma et al., 2023; Ni et al., 2023). The green FinTech concept has gained popularity by incorporating environmentally sustainable practises into the financial sector. It has the potential to play a pivotal role in the advancement of sustainability goals (Tubrazy, 2023).

FinTech instruments like remote monitoring and automation can provide real-time data on mining operations. This high frequency data helps in facilitating comprehensive environmental monitoring and social impact assessments. (Chueca Vergara and Ferruz Agudo, 2021). FinTech can leverage crowdsourcing and citizen engagement to local communities and stakeholders in decision-making involvement. Tools like mobile apps and online platforms can be used by communities to actively participate in monitoring and reporting environmental changes. Including societies leads to social responsibility and ecosystem preservation (Ściślak, 2022). Investors can direct their funds toward these new avenues of mining projects that are committed to environmental sustainability and biodiversity conservation (Catalini and Gans, 2020). Through digital platforms, financial institutions can support mining projects that align with circular economy principles, minimising waste generation and optimising resource efficiency (Du et al., 2022).

As effective systems provision for reporting and monitoring compliance with environmental standards, FinTech contributes to the regulatory compliance maintenance within an organisation. In addition to this, it encourages the transfer of technology in a responsible manner by spreading innovative and environmentally friendly mining practises throughout the industry (Du et al., 2022). The efficient governance of data, a key aspect of FinTech, enhances transparency in reporting and decision-making. Proper data management contributes to informed resource management policies thereby fostering sustainable practices in natural resource extraction and reducing the ecological footprint of mining activities (Challapalli, 2023). In conclusion, it is hypothesised that the promotion of FinTech will help reduce the harmful effects of resource extraction on ecology and biodiversity assessed using the environmental performance index.

4. Methods

4.1. Sample and variables

This quantitative study has availed the data for 37 Asian OBOR countries between 1995 and 2021. As a result of their regional and economic connectivity in the OBOR related projected, this study has also included their spatial interaction. The index of FinTech is developed using the data of new financial sector development index, mobile phone subscriptions, and internet usage. Index of financial development assess the depth, access, and efficiency of financial institutions and financial markets proposed by Svirydzenka (2016). This index is used by studies like H. Liu et al. (2022) which advocated that any indicator of financial development coupled with the mobile phone and internet can represent the intensity of FinTech in the economy (Table 1).

4.2. Equation and estimation methods

This study has constituted the parametrised version of the estimation equation in Equation (1). Here α_1 will assess the spatial autoregression effect where W is the distance weights between the Asian OBOR countries. This arc based, distance-based weight matrix is calculated in GeoDa software by providing the '.shp' file. The matrix multiplication W*EPI required the data to be balanced. This study ensured the selection of a data in a way that there were no missing values or unbalanced data. R software was used for matrix multiplication to calculate WEPI variable. Equation (2) is the short run equation based on the lagged residuals as the convergence coefficient from Equation (1). Equation (3) is the cross-sectional difference equation to calculate spatial long run/direct effect estimates.

$$EPI_{it} = \alpha_0 + \alpha_1 W * EPI_{jt} + \alpha_2 TNR_{it} + \alpha_3 FinTech_{it} + \alpha_4 TNR * FinTech_{it} + \alpha_5 IND_{it} + \alpha_6 PDEN_{it} + e_{it} \text{—} \quad (1)$$

$$\Delta EPI_{it} = \alpha_0 + \alpha_1 \Delta (W * EPI)_{jt} + \alpha_2 \Delta TNR_{it} + \alpha_3 \Delta FinTech_{it} + \alpha_4 \Delta (TNR * FinTech)_{it} + \alpha_5 \Delta IND_{it} + \alpha_6 \Delta PDEN_{it} + \delta_1 e_{it-1} + u_{it} \text{—} \quad (2)$$

$$\Delta EPI_{it} = \beta_0 + \beta_2 TNR_{it} + \beta_3 FinTech_{it} + \beta_4 (TNR * FinTech)_{it} + \beta_5 IND_{it} + \beta_6 PDEN_{it} + e_{it} \text{—} \quad (3)$$

Where $\beta_0 = \frac{\alpha_0}{1-\alpha_1}$, $\beta_2 = \frac{\alpha_2}{1-\alpha_1}$, $\beta_3 = \frac{\alpha_3}{1-\alpha_1}$, $\beta_4 = \frac{\alpha_4}{1-\alpha_1}$, $\beta_5 = \frac{\alpha_5}{1-\alpha_1}$ and $\beta_6 = \frac{\alpha_6}{1-\alpha_1}$.

This study has used a novel technique to estimate the index of FinTech which accounts for the cross-sectional heterogeneity. The index is developed separately for each cross-section and aggregated to form the panel data. The algorithm is developed by authors in R. Empirically, few studies have discussed and used a similar variant (Bai, 2013; Buzick, 2010). The validity of the index will be conducted using the KMO, Bartlett test (Bartlett, 1950), and factor loading of the overall index against the cross-sectional values. The FinTech variable introduces the model as a moderator (Hayes, 2022) with the expectation that higher FinTech improves the sustainability of the natural resource extraction.

This study has used the panel quantile regression algorithm developed by Powell (2022) to control non-normal variables and assess the effects across the distribution of dependent variables; this makes the model robust to distributional heterogeneity. The number of years per cross-section (maximum 27) is sufficiently high to assume that the data is non-stationary (Arshed et al., 2018). The validity of the long run model is ensured using second generation panel cointegration test (Westerlund, 2005) and incidence of convergence coefficient between 0 and -1.

This study has used the Panel ARDL variant specification to address non-stationary nature of variables ~~this~~ and selected the Dynamic Fixed Effect model (Blackburne and Frank, 2007) which is used in literature by Arshed et al. (2022). Since the data is spatially interconnected, the presence of cross-sectional dependence is checked using Pesaran's (2004) method. A study by Liu et al. (2024) used the QARDL model to explore the relationship between FinTech, natural resources, and environmental sustainability while a study by Zhang et al. (2024) used second generation panel data model for BRICS countries to account for cross sectional dependence.

Unlike other econometric models SAR (Elhorst, 2014), which deploy robustness to dependence, this study has used the Spatial Autoregressive Model using distance weights to account for the spatial effects. The SAR model was used to assess the determinants of CO_2 in OBOR countries (An et al., 2021; Ashraf et al., 2022; Jiang et al., 2021; Yin et al., 2021). Similarly, one study uses such a spatial model to estimate environmental quality (Espoir and Sunge, 2021). The notion behind the use of spatial interlinkage lies behind the OBOR projects itself which interconnects the country via logistics and trade.

Thus, the final model will provide estimates in short run and long run in the time domain, short run and long run, and direct and indirect in the spatial domain, and at different positions of EPI in the quantile domain of the data making the estimates efficient.

Table 1
Variables and data sources.

Variable name (Symbol)	Definition and Units	Data Source
Ecological Sustainability (EPI)	Environmental performance index (0–100)	Wolf et al. (2022)
Natural Resource Market (TNR)	Total natural resource rents as a percent of GDP	WDI (2021)
Industrialisation (IND)	Industry sector value addition as a percent of GDP	WDI (2021)
Population Effect (PDEN)	Population per sq. km area of the country	WDI (2021)
Financial innovation/ FinTech (FinTech)	Index of financial sector development (FD), mobile phone subscriptions per 100 people (MOB), and individual Internet usage as percentage of population (INT)	Self-constructed using the data from Svirydzenka (2016) and WDI (2021)

5. Results and discussions

The results start with a discussion of index construction using the cross-sectional heteroskedasticity method. Fig. 1 shows the overall KMO as a dotted horizontal line and cross-sectional KMO values. Here, other than five countries, others have acceptable KMO. Similarly, Fig. 2 shows that all of the cross sections have significant Bartlett's test values supporting the index that has been constituted. In Fig. 3, the scree plot shows that one index suits the three variables.

Fig. 4 provides the cross-sectional incidence of factor loading values. Here, only a few countries, such as Qatar, Oman, and Jordan, show the negative factor loading of financial sector development while other countries show positive factor loading values. Fig. 5 further compares the index made using standard factor analysis which assumes that the data is pooled (indexhhom) with the cross-sectional heteroskedastic factor analysis (indexhet), allowing for the country differences. Here, it is noted that, in most cases, the box plots are overlapping.

Fig. 6 plots the FinTech index in the Asian OBOR countries. Here, warmer colours show a high incidence of FinTech and, when compared with Fig. 7 where EPI has been plotted, there is a slight positive association. This slight positive spatial correlation is also confirmed using the bivariate Moran's I using distance weights.

Table 2 presents univariate descriptive and inferential statistics of the variables used in the study. Comparing mean and standard deviation showed that TNR and FINTECH are over-dispersed while other variables are under-dispersed across the sample. The mixture of under- and over-dispersed variables led the authors to expect the cross-section heteroskedasticity to be present in the data. This will be handled using the panel data regression method.

Secondly, based on skewness, kurtosis, and three types of normality tests, it can be seen that the data is not normally distributed. Additionally, Fig. 8 also adds that the correlations between TNR and EPI vary across different quantile positions of EPI indicating distributional heteroskedasticity. Both pieces of evidence led this study to use the quantile regression methods.

The VIF values of independent variables are less than two showing no indication of multicollinearity in the model. Meanwhile, the significant cross-sectional dependence (CD) test shows that the data is cross-

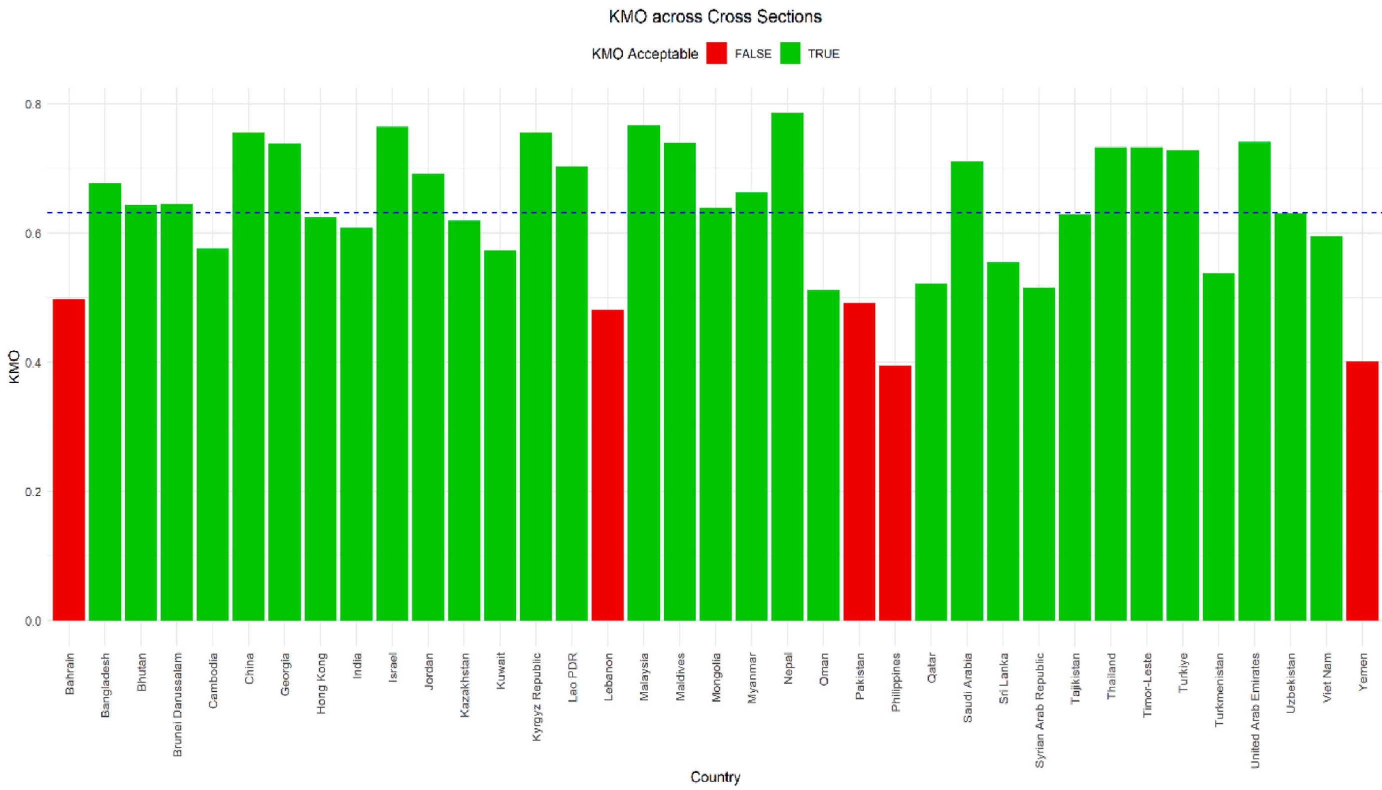

Fig. 1. Cross-sectional specific KMO values.

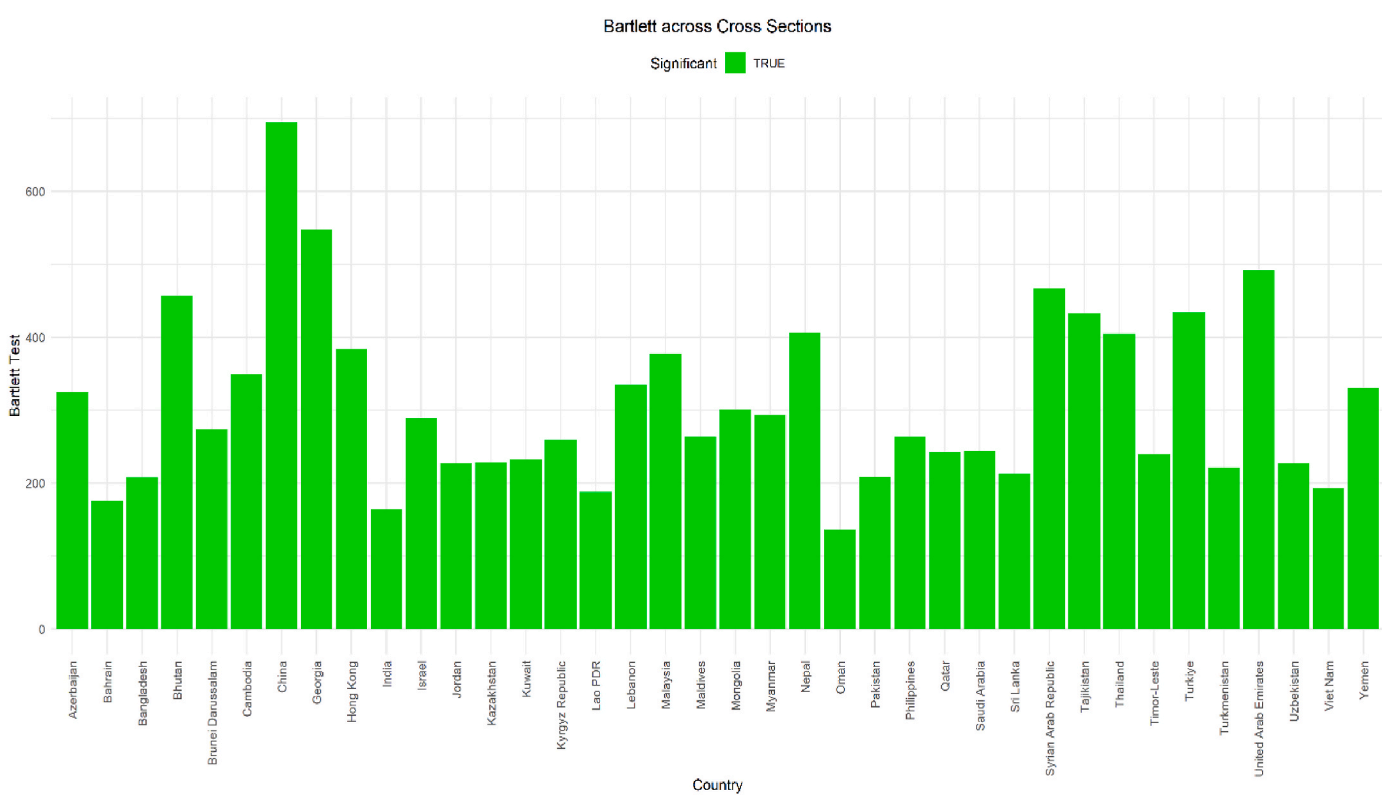

Fig. 2. Cross-sectional specific Bartlett's test.

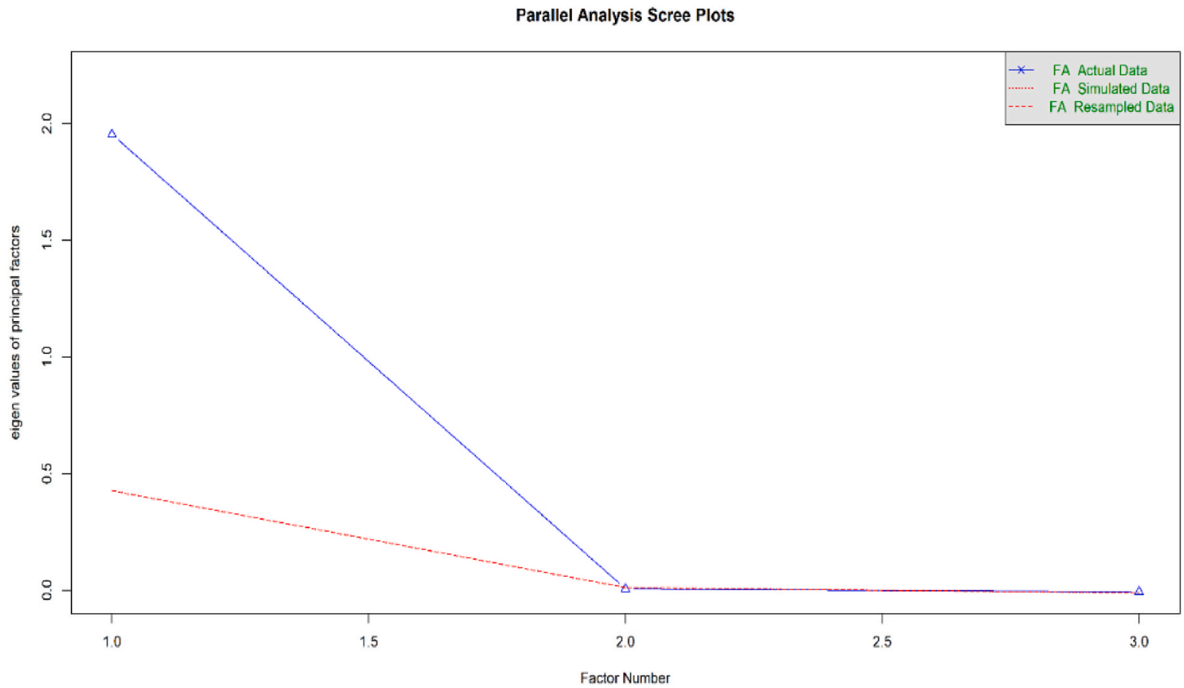

Fig. 3. Scree plot.

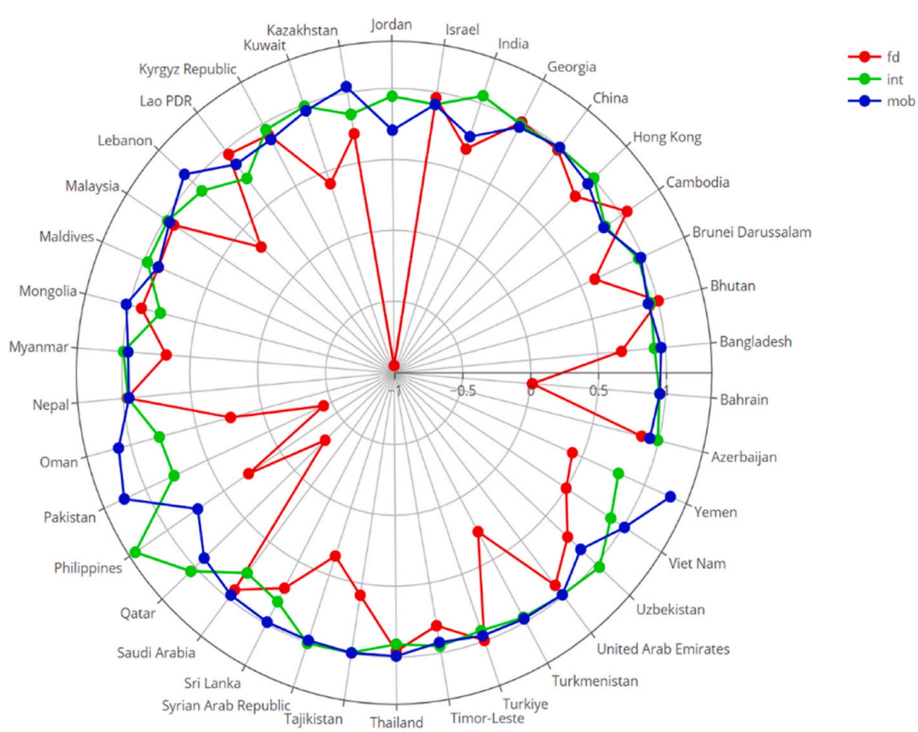

Fig. 4. Cross-sectional specific factor loading.

sectionally autocorrelated. Empirically, studies have used second-generation panel date models to address this problem (Arshed et al., 2023) but this study resorts to using the spatial econometrics approach to include spatial autoregressive variables.

Fig. 9 presents the correlation among the variables of the study. Here TNR, FinTech, and PDEN correlate negatively with EPI while IND has a positive correlation. Further, while comparing the correlations of independent variables it is observable that there is no high correlation between independent variables, excluding the chance of multicollinearity.

Lastly, Fig. 10 shows that when the value of FinTech is above average the association of EPI and TNR improves from negative to slightly positive. This evidence led this study to propose that FinTech positively moderates the EPI and TNR relationship.

Table 3 presents the second generation panel cointegration test for the selected specification. Here it can be seen that for both variants of Westerlund's (2005) test, there is an evidence of acceptance of alterative hypothesis concluding that there is cointegration.

Table 4 provides the estimates in several dimensions. The second

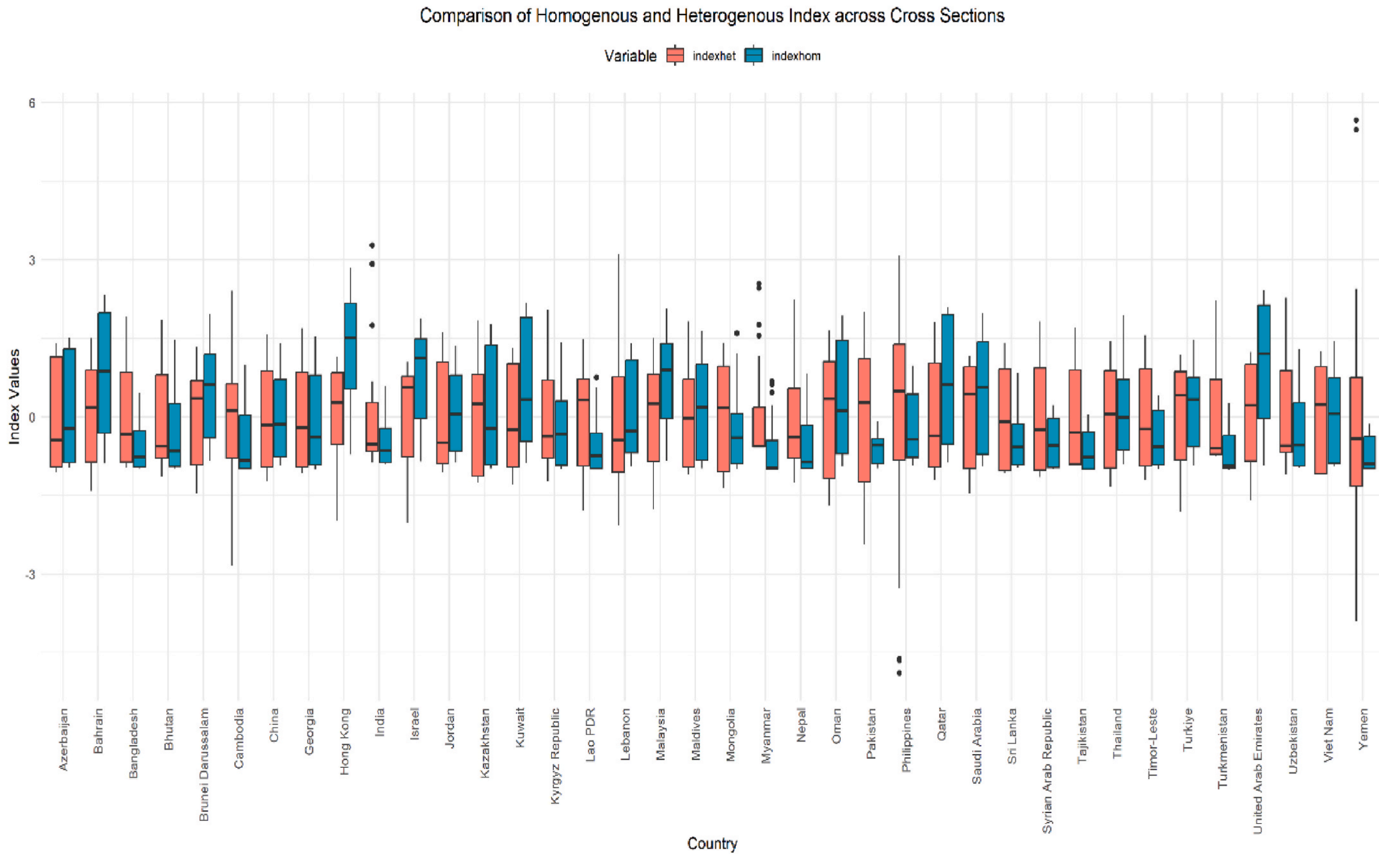

Fig. 5. Cross-sectional comparison of overall and heteroskedastic index.

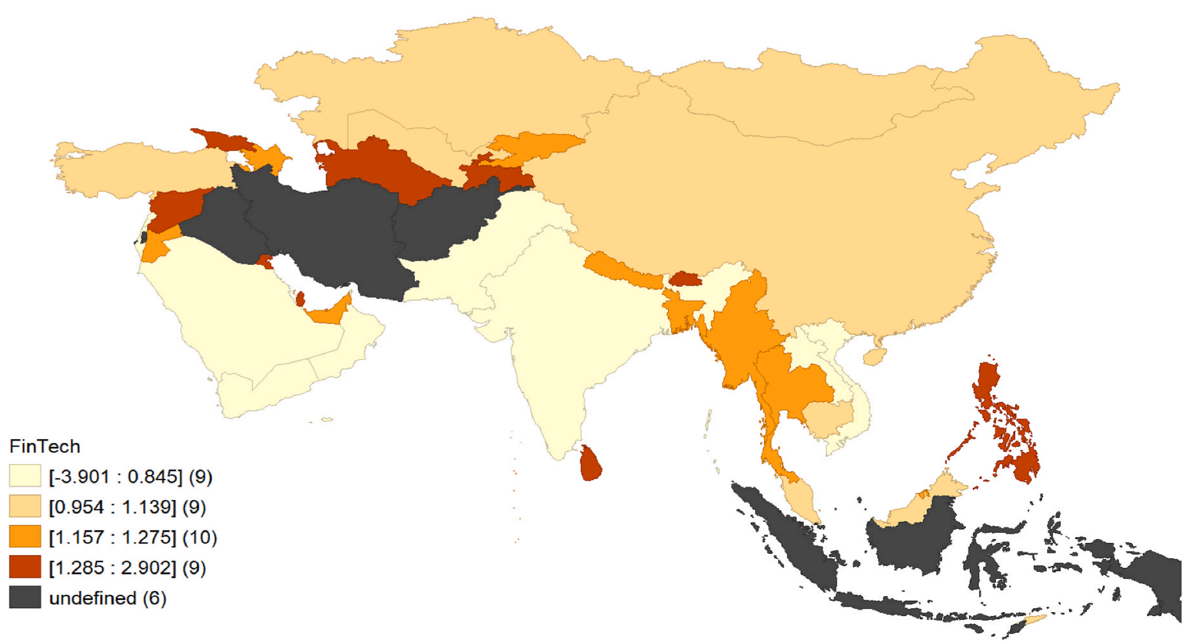

Fig. 6. Geographic distribution of FinTech index (most recent available value).

column provides the long run estimates at median in time series domain while the SR effect in Spatial domain is based on Equation (1). Columns three to six are variants of this estimate at different quantile positions 20, 40, 60, and 80 respectively. The last column is the LR/Direct effect in the spatial domain based on Equation (3).

The estimates are based on 921 overall observations from 37 countries. The significance of the Wald test confirms that the overall model is a fit. Along with Table 4, Fig. 11 is interconnected. Fig. 4 presents the line chart for long run slope coefficient for each variable at different quantile positions.

In the time series domain, it can be seen that a 1% increase in population density (PDEN) and industrialisation (IND) tend to reduce EPI by

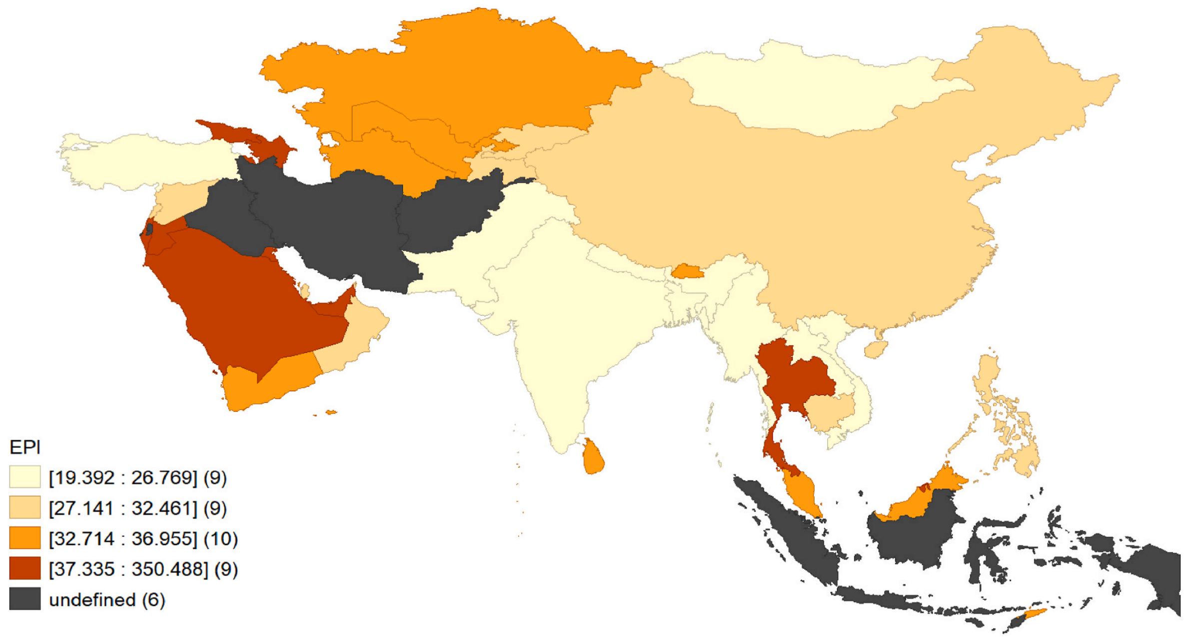

Fig. 7. Geographic distribution of EPI index (most recent available value).

Table 2
Univariate descriptive and inferential statistics.

Stat	EPI	TNR	FINTECH	PDEN	IND
Mean	36.61	12.14	0	219.68	30.61
Median	29.49	4.55	−0.14	89.47	30.80
Std. Dev.	7.41	14.82	1.11	339.51	14.29
Skewness	0.71	1.39	0.21	2.80	0.69
Kurtosis	3.21	4.38	4.25	10.92	3.01
Jarque Bera	58.15	171.72	29.76	444.68	50.04
Prob	0.00	0.00	0.00	0.00	0.00
S-Wilk	7.80	11.96	8.38	13.62	7.52
Prob	0.00	0.00	0.00	0.00	0.00
S-Francia	7.33	11.20	7.70	12.75	7.26
Prob	0.00*	0.00*	0.00*	0.00*	0.00*
VIF[a]	–	1.65	1.61	1.08	1.67
CD[b]	2.05	38.86	91.96	103.86	7.77
P value	0.04*	0.00*	0.00*	0.00*	0.00*

Legend: a – Variance Inflation Factor, b – Cross sectional dependence. * Significant at 1%.

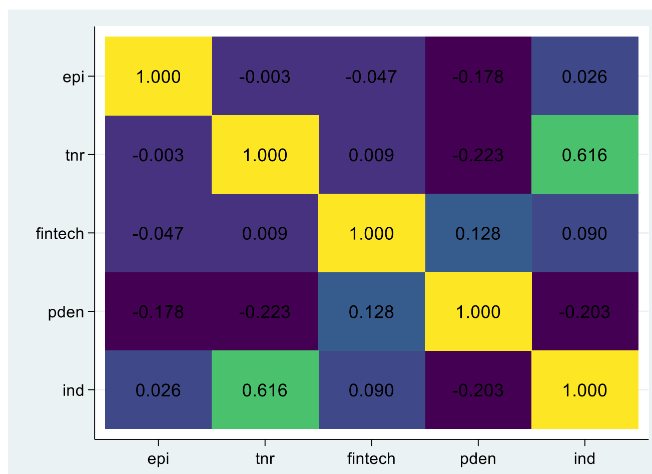

Fig. 9. Pairwise correlation matrix.

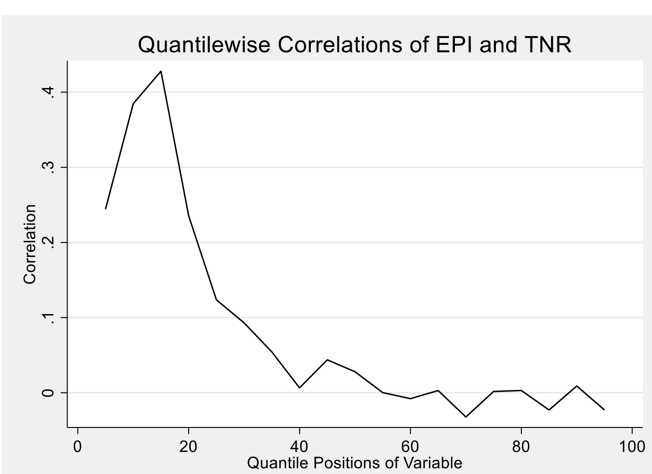

Fig. 8. Quantile-wise correlation between EPI and TNR.

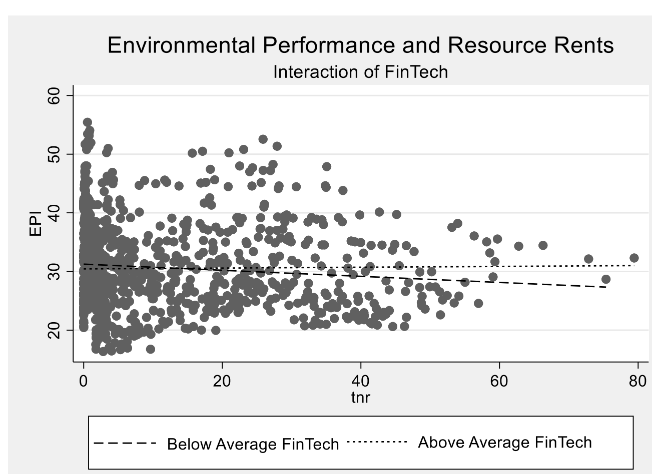

Fig. 10. Scatter plot with FinTech contrasts.

Table 3
Panel Cointegration test.

Test	Alternative Hypothesis	Statistic	P.value
Variance ratio	All Panels Cointegrated	−1.285	0.099**
Variance ratio	Some Panels Cointegrated	−2.237	0.012*

Legend: * significant at 5% and ** significant at 1%.

0.002% and 0.126% at medians respectively. The negative effect of industrialisation is consistent across percentiles while population density tends to hover around zero with alternative positive and negative values. These results are also visible in Fig. 11.

With a 1% increase in FinTech, the direct effect of FinTech increases the EPI by 0.567% on average. The effect of FinTech is positive for low to medium percentiles of EPI while at higher percentiles FinTech tends to have a negative effect, visualised in Fig. 11. There are two ways this can be explained; the first is the law of diminishing returns whereby only increasing FinTech would diminish its effect and the second is that higher FinTech will also boost growth as a scale effect leading to pressure on resource utilisation and harmful effects of economic activity.

While exploring the natural resource extraction and moderating effect, it can be seen that one unit increase in natural resource rents (TNR) tends to reduce EPI by 0.108 percent at medians. There is a negative and consistent effect of TNR on EPI across quantiles which is also visualised in Fig. 11.

Further, the cross-product is positive, showing that for every 1% increase in FinTech the marginal effect of TNR to EPI increases by 0.011% at medians. This negative effect is visible in all quantiles except for 60 percentiles, also shown in Fig. 11. The negative moderating effect is increasing at higher percentiles of environmental performance, for example it is −0.023 at 80 percentile of EPI. This shows that in the economies that have high EPI values they are experiencing a stronger

Table 4
Timeseries and Spatial Long Run estimates.

Variables	Coeff. @ median (Prob)	Coef @ 20 percentile	Coef @ 40 percentile	Coef @ 60 percentile	Coef @ 80 percentile	Spatial LR/Direct Effect
TNR	−0.108 (0.000)*	−0.071	−0.099	−0.038	−0.095	−0.104 (0.000)*
TNR*FINTECH	0.011 (0.000)*	−0.002	−0.012	0.008	−0.023	0.011 (0.000)*
FINTECH	0.567 (0.000)*	0.354	0.351	−0.372	−0.202	0.546 (0.000)*
PDEN	−0.002 (0.000)*	0.0005	−0.002	0.0008	−0.008	−0.002 (0.000)*
IND	−0.126 (0.000)*	−0.066	−0.109	−0.082	0.015	−0.122 (0.000)*
W*EPI	−0.038 (0.000)*	0.030	−0.043	0.043	−0.004	–
Sample	921	Countries	37	Wald (prob)	79,632	0.00*

Legend: * significant at 1%.

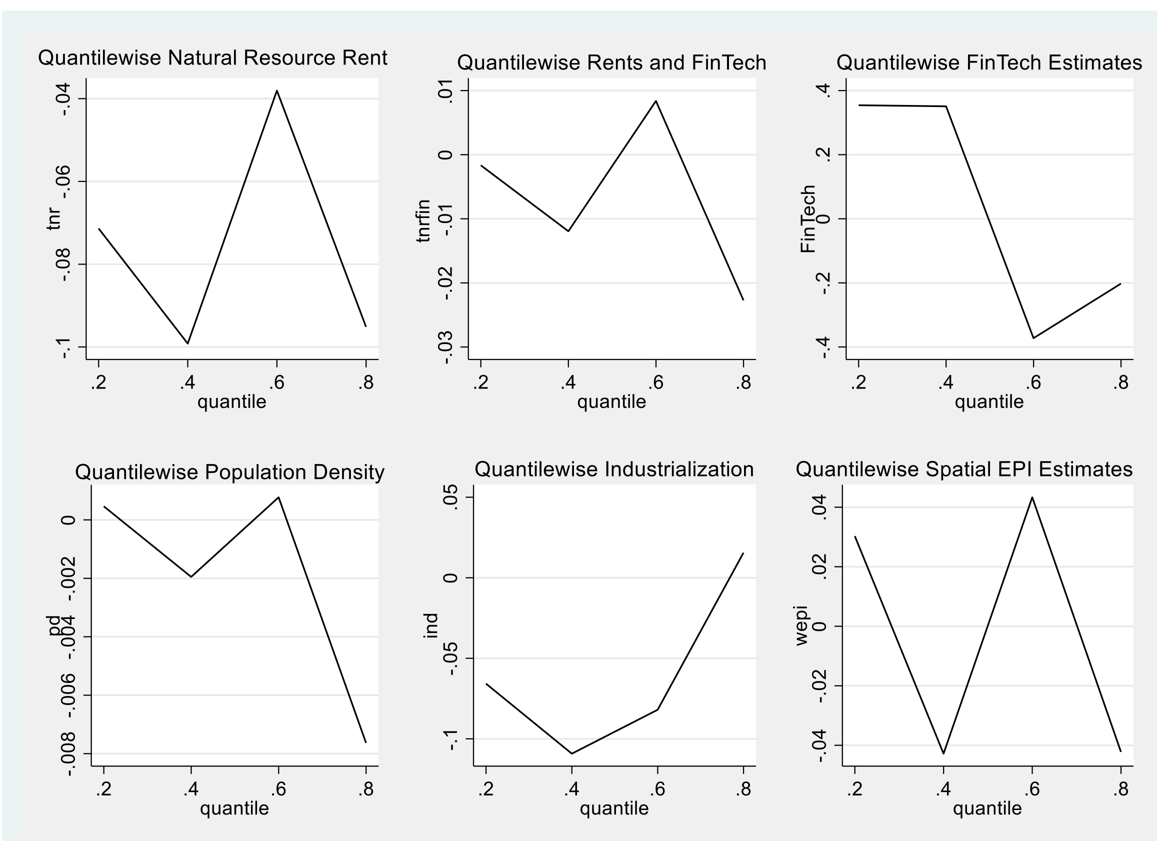

Fig. 11. Quantile-wise timeseries long run estimates at different quantiles
Note: The top left chart is the quantile-wise long run slope coefficient of TNR variable. The top middle is the quantile-wise long run slope coefficient of TNR*FinTech variable. The top right is the quantile-wise long run slope coefficient of FinTech variable. The bottom left chart is the quantile-wise long run slope coefficient of PD variable The bottom middle is the quantile-wise long run slope coefficient of IND variable and the bottom right is the quantile-wise long run slope coefficient of WEPI variable.

negative moderating effect of FinTech. This indicates the need to find the balance between the use of natural resources and integration of FinTech as ecologically diverse nations are sensitive to changes in the use of natural resources integrated with technology.

Figs. 12 and 13 visualise the moderating effect of FinTech on the TNR-EPI relationship in the spatial short run and spatial long run respectively using Dawson's (2013) algorithm. In both cases, it is evident that countries enjoy high sustainability with an increase in FinTech.

Here, the spatial effect (W*EPI) is negative which shows that, at median, an increase in EPI in neighbouring countries reduces EPI in this country. This shows that any intervention to improve EPI in one country tends to have a negative effect on EPI in neighbouring countries which can be explained by the fact that the environmental regulation that improves EPI in a country will displace the polluting activities to other countries in the region leading to fall in EPI. This regulation will have positive direct and negative indirect effects (Burden et al., 2015; Golgher and Voss, 2016).

Thus, after adjusting for the negative spillover effect, the spatial direct effect would be a smaller positive or larger negative. Observing the last column in Tables 3 and it is noted that the negative net effect of TNR, PDEN, and IND are larger while it is also diminishing the positive direct and moderating effect of FINTECH. This points towards a need for regional intergovernmental policy regulation to cater to the negative spillover effects.

Table 5 provides the time-series short run estimates using the sample of 883 observations. These estimates are based on the 2-Step ECM method (Arshed et al., 2022; Ul-Durar et al., 2023). Here, the EPIt-1 is the negative and significant convergence coefficient, confirming that the long run model is suitable for policy intervention. Fig. 14 points out that with the increase in EPI, the convergence coefficient value reduces to zero which means that the effectiveness of the model diminishes at higher quantiles of EPI.

6. Conclusion and discussions

China's BRI initiative to improve connectivity within and across Asia has led to an increase in multiple infrastructural projects in which around 130 countries are interested. Initiating these projects led to increased road networks, energy extraction, energy production, and economic growth. This project has increased the connectivity among the countries with rail and road network leading to higher cross-country dependencies. With increased extraction of natural resources and trans-country infrastructure development, this initiative faces concerns about disturbing the habitat, ecosystem, and biodiversity of the regions. With an aim to find a balance between resource extraction and environmental performance, many studies have explored means to improve resource management with the aim of achieving sustainability. This study proposes FinTech as a potential driver of financial innovation and accountability which can help improve resource management efficiency. This study estimates the moderating role of FinTech in achieving sustainability in resource sustainability while accounting for spatial and time dependency of the data for the Asian - OBOR countries.

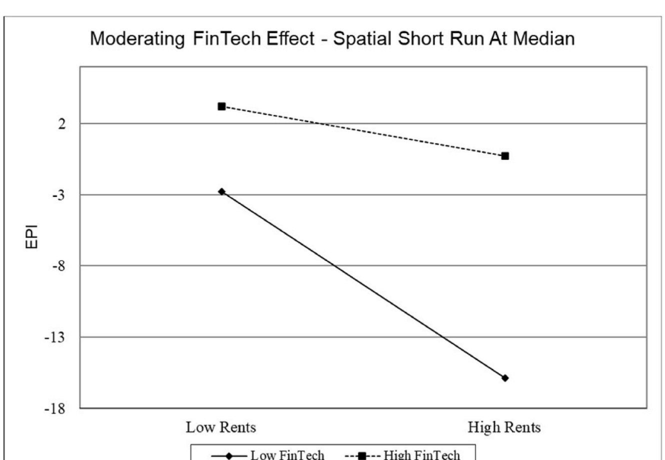

Fig. 12. Spatial Short run Moderating effect of FinTech.

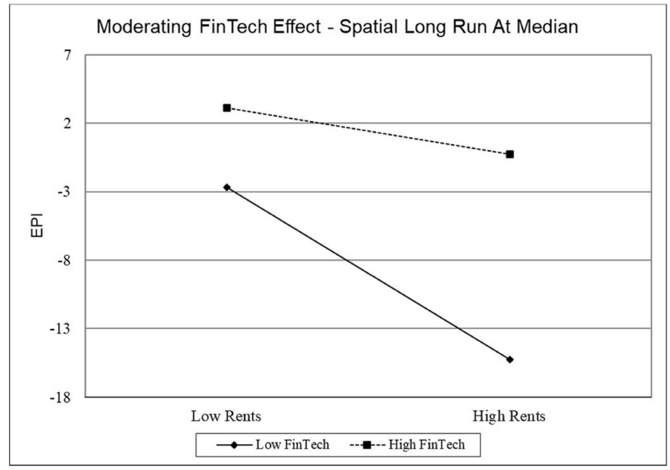

Fig. 13. Spatial Long run moderating effect of FinTech.

Table 5
Short run quantile ARDL (dependent variable EPI).

Variables	Coef (Prob)
ΔTNR	−0.017 (0.000)*
Δ(TNR*FINTECH)	0.006 (0.000)*
ΔFINTECH	−0.182 (0.000)*
ΔPDEN	−0.004 (0.000)*
ΔIND	0.004 (0.028)**
Δ(W*EPI)	0.047 (0.000)*
EPI_{t-1}	−0.004 (0.000)*
TNR_{t-1}	−0.004 (0.000)*
$(TNR*FINTECH)_{t-1}$	0.009 (0.000)*
$FINTECH_{t-1}$	−0.052 (0.000)*
$PDEN_{t-1}$	0.0001 (0.230)
IND_{t-1}	0.0003 (0.747)
$(W*EPI)_{t-1}$	0.006 (0.000)*
Sample	883

Legend: * significant at 1%, ** significant at 5%.

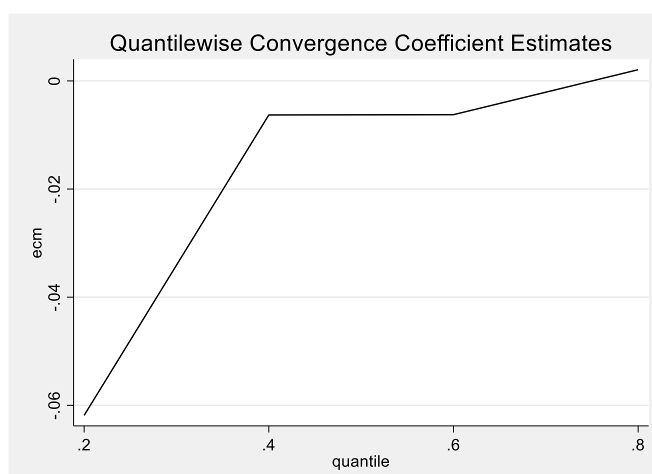

Fig. 14. Quantile-wise plot of Convergence coefficient.

This study has innovated in the estimation of the model in multiple ways. Firstly, the constitution of the FinTech index is performed using cross-sectional heterogenous factor analysis to account for country differences in panel data by developing algorithm in R. Secondly, this study has used the Panel Quantile ARDL model with Dynamic Fixed Effect Specification to account for non-stationary variables which provides a distribution robust long run relationship. Lastly, this study incorporated the spatial distance weight matrix to develop a spatial autoregressive (SAR) model within the QARDL model. With this, the estimates one side explores the long run horizon in time domain. It also explores the long run horizon in the cross-section domain thus also making the model robust to cross sectional dependence.

The results showed that FinTech has a direct effect in improving environmental performance but this effect becomes negative at higher quantiles because of the scale effect on economic growth-led energy demand. However, the moderating effect still remains fruitful in making natural resources sustainable. This study surprisingly points out a need for intergovernmental regulation in order to evade negative spill over effects on environmental performance arising from displacement of polluting activities. Intergovernmental agencies and associations should encourage countries to adapt to environmental standards in developing their infrastructure projects and reduce their reliance of fossil energy.

Based on the assessment, this study has arrived at the following policy implications. FinTech has shown a promise in ensuring sustainability from resource extraction but there is still massive diversity among the Asian OBOR countries in terms of FinTech adoption. Governments should facilitate the supportive aspects of FinTech in greenifying the resource markets. The scale effect of FinTech should be matched with the effort to reduce reliance of fossil energy so that it can mitigate the harmful effect on ecosystems.

Estimations showed that better institutional performance in one country may lead to harmful spill over in other countries. OBOR must develop a support fund to help effecting countries in mitigating the harmful effects on biodiversity and environmental performance.

Future studies can explore complicated variants of spatial models to assess if the spillovers arrive from policy/independent variables. The use of hybrid models can help gather higher order information from the same data. The disaggregated resource rents effect may also be explored in terms of the effectiveness of FinTech for sustainability and the model can be transformed to include the cross-sectional averages to assess the spillover effects over time, along with the spillover effects across cross-sections using the SAR specification.

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.

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CRediT authorship contribution statement

Shajara Ul-Durar: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Marco De Sisto:** Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Investigation, Conceptualization. **Noman Arshed:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Shabana Naveed:** Writing – review & editing, Writing – original draft, Methodology. **Madiha Rehman Farooqi:** Writing – review & editing, Writing – original draft, Resources.

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

Data will be made available on request.

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