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Toward fostering environmental innovation in OECD countries: Do fiscal decentralization, carbon pricing, and renewable energy investments matter?

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ABSTRACT

Environmental innovation is an integral part of sustainable development goal (SDG) 9. It also provides the foundation for green energy production, and thus, indirectly supports the accomplishment of SDG 7. Notably, the energy transition from fossil fuel to renewables is critical for achieving sustainable development and a cleaner environment. Therefore, this study explores the major driving forces of environmental innovation in 29 OECD countries from 1993 to 2019 by incorporating environmental taxation, carbon pricing policy, budget for renewable energy development and demonstration, regional authority, financial development, and globalization. The recently proposed Quantile via Movements methodology is employed to address the spiral dependence of explanatory variables and obtain results at different quantiles. The findings of Quantile via movements reveal that enhancing environmental taxation and strengthening carbon pricing policies encourage environmental innovation. Moreover, these countries should decentralize policymaking and delegate authority to regions. Alongside this, policymaking for encouraging the private sector budgets for renewable energy development and demonstration is necessary. The stringent policy regulations at the regional level can enhance the innovation of domestic industries concerning the development, adoption, and commercial competitiveness of environment-friendly technologies. Furthermore, the financial sector's development enhances environmental innovation, while globalization needs to be properly regulated.

1. Introduction

The unprecedented upsurge in environmental deterioration and climatic changes pose a grave threat to this planet and human life (Abbas, 2022; Abbas et al., 2022; Shahbaz et al., 2021; Sinha, 2017; Sinha et al., 2022). Therefore, a major contemporary challenge for the global community is to keep temperature rise below 2 degrees Celsius above the pre-industrial level by 2050 (United Nations, 2022). This challenge entails almost net-zero greenhouse gases emission. Thus, the major focus of the Sustainable Development Goals (SDGs) of the United Nations is to achieve sustainable and clean economic growth. For instance, SDG-7 (affordable and clean energy) and SDG-13 (climatic actions) urge for energy transition toward clean sources and the adoption of various adaptative and mitigation strategies to cope with environmental degradation and climatic changes. Progress on these SDGs cannot be achieved without innovation as innovation can impact both SDG-7 and SDG-13. Hence, innovation is kept as an integral component of SDG-9, which focuses on innovation, infrastructure, and industrialization. Therefore, sustainable development requires transforming the energy sector, industrialization, and infrastructure through innovation.

Policymakers at the COP26 summit urge technologically advanced OECD countries to focus on the development of environmentally friendly technologies to realize environmental and ecological sustainability (OECD, 2021). The global progress on SDGs

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is dependent on the innovative capacity of OECD countries concerning environment-friendly technologies (Harrabin, 2021). Environmental innovation depends on the efficient management of economic, social, societal, and governance drivers to facilitate technological efficiency and energy transition (Khan et al., 2022). For instance, environmental taxation and carbon pricing policies can encourage environmental innovation by increasing the cost of carbon-intensive technologies (Saha et al., 2022). Furthermore, the private sector budgets for renewable energy development and demonstration (BRDD) along with financial development and globalization can also influences environmental innovation for energy transition (Bilal et al., 2022). The plausible importance of these factors in environmental sustainability and energy transition urges for constructing a comprehensive model that could be used to analyze their impacts on environmental innovation. Fig. 1 depicts environmental innovation in OECD on the map while Fig. 2 reveals that the innovative capacity of sampled OECD countries is restricted below 4 percent of total environmental innovation. Therefore, this study aims to model the behavior of environmental innovations in global technological leading countries.

The prior empirical studies have mainly focused on determinants of environmental degradation along with exploring the impacts of environmental innovation on the environment and climatic conditions (Bilal et al., 2022; Hassan et al., 2023, 2022a, 2022b; Mongo et al., 2021; Tauseef Hassan et al., 2022). However, insufficient investigations have focused on drivers of environmental innovation. Among these works, literature that focuses on firm-level drivers for environmental innovation, following the Porter (1991) hypothesis, urges for the imposition of environmental regulations to enhance innovative efficiency and commercial competitiveness (Bauer et al., 2012; Blind, 2012; Horbach, 2008; Liao et al., 2018). While, the aggregate country or regional-level studies on drivers of environmental innovation have focused mainly on environmental regulations, environmental taxation, and gender bias (Horbach, 2008; Irfan et al., 2022; Saha et al., 2022). Prior literature has largely overlooked the impacts of carbon pricing policy, budget for renewable energy development and demonstration (BRDD), fiscal decentralization, financial development, and globalization on environmental innovation.

Therefore, this research increases the scope of available literature by including these important drivers to explain environmental innovation in OECD countries. The major research questions are summarized below.

What are the major drivers of environmental innovation across OECD countries?

Several strains of factors motivated authors to conduct this econometric inquiry. First, the shift from fossil fuel to clean energy, which comprises three stages: invention, innovation, and diffusion, is crucial to address environmental deterioration and related climatic changes (Saha et al., 2022). This process of the energy transition is dependent on the innovative capacity of advanced countries in the OECD (OECD, 2020). Given the urgency of the clean energy transition, OECD countries have implemented numerous policy measures to foster environmental innovation, such as the imposition of taxes on environmental emissions and the adoption of a carbon pricing policy. The imposition of environmental taxation and carbon pricing can enhance environmental innovation by increasing the cost of environment-polluting industries/technologies. Second, the development of new technologies requires considerable budgetary allocation for research and development activities. The private sector BRDD plays a very important role in the development of renewable energy technologies. Moreover, the findings of Lee and Min (2015) reveal that the BRDD can con-

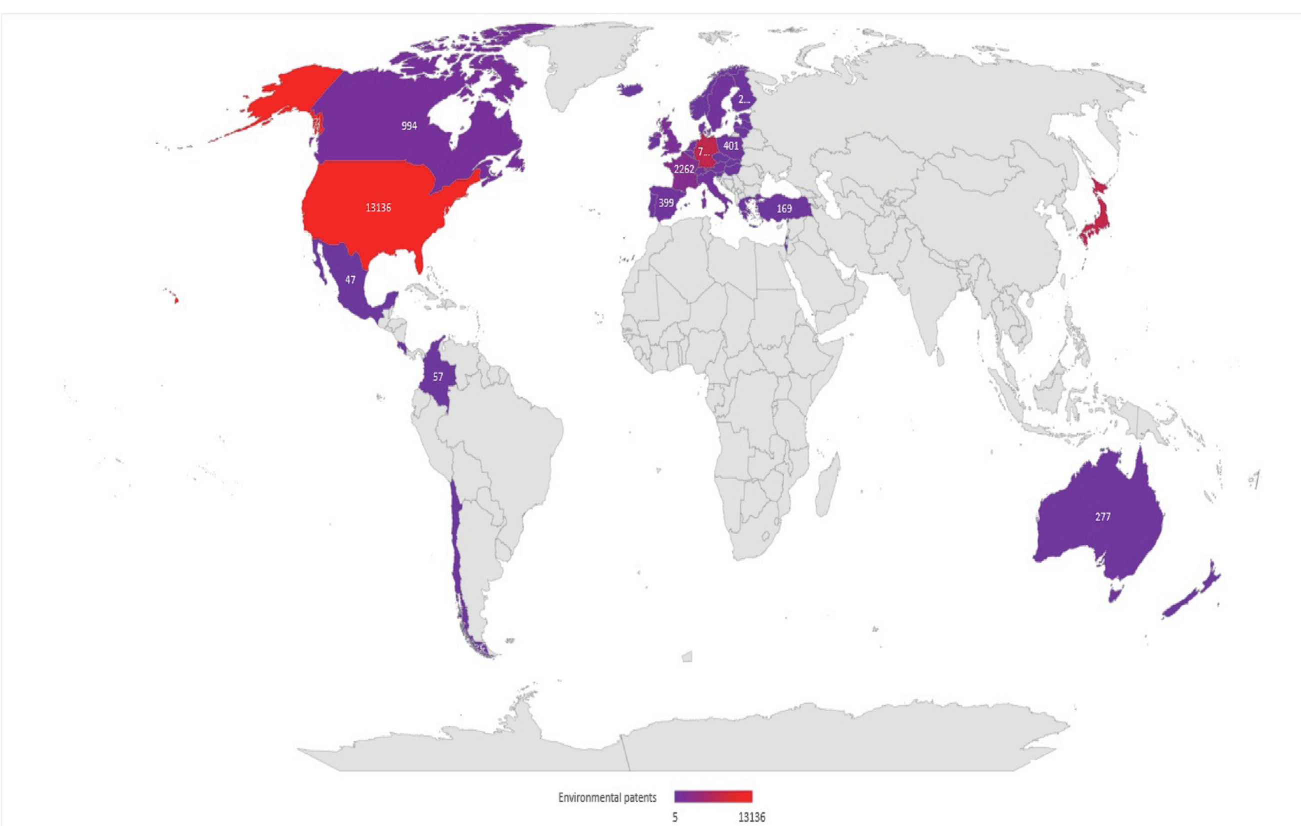

Fig. 1. Environmental innovation in selected OECD countries.

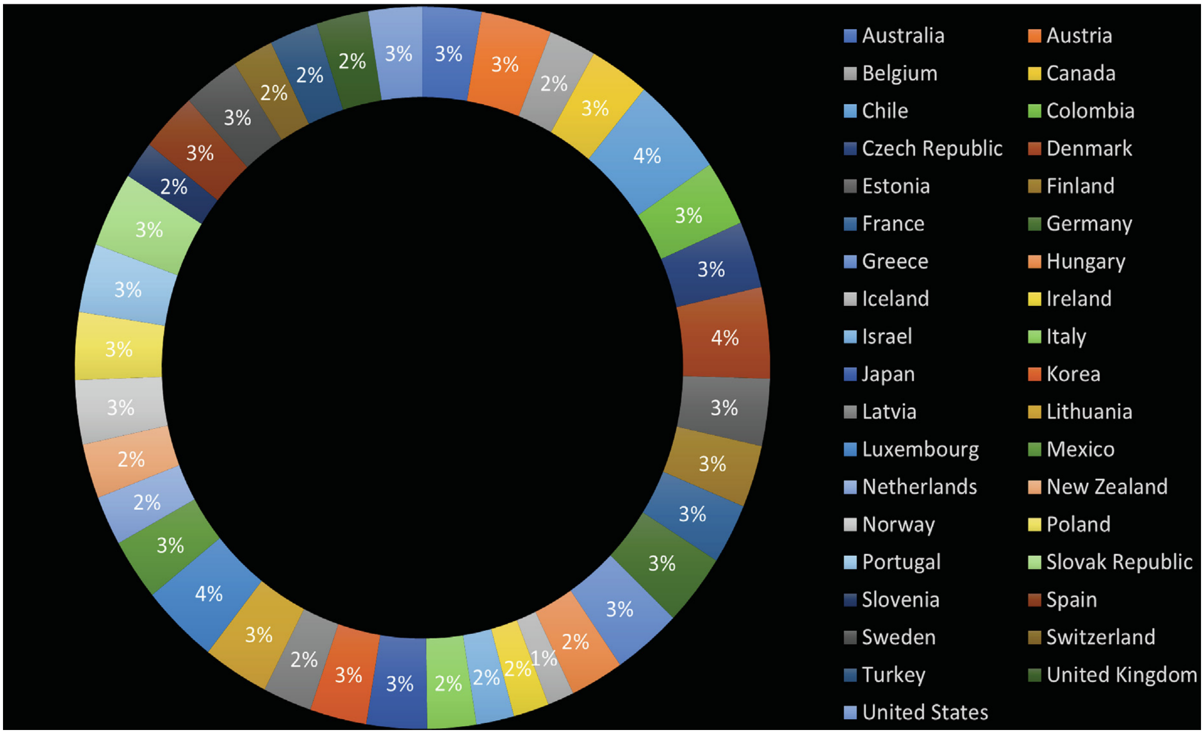

Fig. 2. Distribution of environmental innovation across OECD countries.

siderably reduce greenhouse gas emissions. However, the impact of BRDD on environmental innovation is largely overlooked.

Third, the policies implemented at regional levels have much better influence over industries operating in those areas to adopt and implement environmental regulations as compared with centralized policies (Hu et al., 2022). Therefore, OECD countries have adopted two policy regimes at the central and regional levels. The regional level governments are responsible for more than 60 percent of total public investment and 69 percent of subnational government expenditures (OECD, 2020). Moreover, the findings of Hu et al. (2022) found a significant positive impact of regional authority on energy transition in OECD countries. However, the impact of regional authority on environmental innovation has been overlooked. Therefore, this study explores the impact of regional authority on environmental innovation. Fourth, financial development and globalization can provide an important role in the process of environmental innovation. Prior empirical studies have examined the effects of financial development and globalization on carbon dioxide emissions (Ahmad et al., 2022a; Baloch et al., 2021; Bilal et al., 2022; Taghizadeh-Hesary et al., 2022), while their effects on environmental innovation capacity have been overlooked. Therefore, this study examines whether financial development and globalization enhance or distort the innovation capacity of OECD countries concerning environmental technologies.

Several factors make this study different than the previous literature on environmental innovation. First, it constructs a model to explore the effects of BRDD, carbon pricing policy, and regional authority on environmental innovations along with other explanatory variables. As discussed above, the impacts of some of these factors on environmental innovation have been overlooked in the past literature. Second, the panel data combines heterogenous cross-sections over an extended time. Therefore, the behavior of macroeconomic variables can vary across quantiles. Furthermore, the spiral dependence among explanatory variables can distort the efficiency of estimation. The prior empirical studies on environmental taxation mostly relied on traditional panel data analysis and overlooked these characteristics. This study expands the scope of existing literature by employing recently advanced panel quantiles via movements that can address heterogeneous effects across various quantiles along with addressing spiral dependence. Third, this study directs several policy implications in line with the SDGs agenda to enhance environmental innovation. The findings of this study reveal that environmental taxation, carbon pricing, BRDD, and devolution of authority to regions can enhance the innovative capacity of OECD countries to produce new environment-friendly technologies.

The remaining parts of this research are constructed in the following pattern: Section 2 provides empirical and theoretical literature, while section 3 elaborates on methodology and data. Section 4 discusses the findings of the study, whereas section 5 provides the conclusion of the study.

2. Literature review

Innovation in environmental technology can enhance global resilience capabilities and thus, improve environmental quality and address climatic changes (European Environment Agency, 2011). Many studies have inspected the role of environmental innovation in environmental degradation, for instance, Wei and Lihua (2022) for ASEAN, Hussain and Dogan (2021) for BRICS, Hussain et al. (2022) for emerging nations, Chu (2021) for OECD economies, Chien et al. (2022), and Xin et al. (2021) for China. However, literature on drivers of environmental innovation from countries' perspectives is relatively scarce. Therefore, this section discusses firm-level and national/regional-level drivers of environmental innovation.

The considerable increase in demand for innovative products along with the innovative capacity of firms engaged in the production process boost firm-level environmental innovation. Besides, demand and supply side considerations and a plethora of other factors can influence firms' ability to innovate environment-friendly technologies. For instance, Porter's hypothesis urges for the imposition of environmental regulation to enhance the innovative capabilities of firms, which also improves their commercial competitiveness (Porter, 1991). Brunnermeier and Cohen (2003) conclude that an increase in public spending relating to pollution abatement along with an increase in monitoring and enforcement of environmental regulations can enhance innovative capacity. Furthermore, Horbach (2008) urges for an increase in research and development spending along with environmental regulation, environmental management, and general organization changes to enhance firms' capacity to innovate. While Ghisetti and Pontoni (2015) by using *meta*-data analysis show that technology push, market pull, policy push–pull, and firm-specific factors considerably enhance environmental innovation. It implies that both firm-specific and country-specific factors can influence the firm's ability to embark on environmental innovation. The focus of this study is to explore the impacts of aggregate country-specific drivers on environmental innovation.

2.1. Environmental taxation and carbon pricing

Environmental taxation and carbon pricing are important policy instruments that force domestic firms/industries to innovate and adopt environment-friendly technologies by increasing the cost of production of environment-polluting technologies. Prior empirical literature reveals significant positive impacts of environmental taxation and other environmental policy stringencies on environmental innovation. For instance, Dechezleprêtre and Glachant (2014) explore the impact of domestic and foreign environmental policies on the development of wind power across the OECD countries. The finding reveals that these environmental policies are a major driver for wind power development and adoption across the OECD countries. A similar argument concerning the effectiveness of environmental regulations on the production of innovative environmental technologies in 21 OECD countries is validated by Blind (2012). Similarly, Liao et al., (2018) conclude that taxation and environmental regulation enhances Chines firms' capacity for environmental innovation.

Nevertheless, the recent study by Wang and Yu (2021) unfolds that environmental taxation policy can considerably enhance the efficiency of green technology innovation in China's resource-based industries. This proposition is also validated in 42 high and middle-income countries by Karmaker et al. (2021). The findings reveal that a 1 percent increase in environmental taxes can increase environment-friendly technological innovation by 0.57 percent and 0.78 percent in high and middle-income countries, respectively (Khan et al., 2021). Furthermore, Saha et al. (2022) constructed a model to explore the effect of environmental finance on environmental innovation in 38 OECD countries from 1990 to 2019. The finding reveals that environmental taxation has a significant positive impact on environmental innovation, while gender inequality dampens the potential of green financing to boost innovations. The findings urge for more gender inclusivity to enhance environmental innovation capabilities. The findings of these studies reveal that environmental taxation is an important tool to enhance the development of environment-friendly technology. However, the literature has overlooked the impact of carbon pricing policy on environmental innovation.

2.2. Research and development

The development of new technology requires considerable budgetary allocation to foster research and development activities. Horbach (2008) noted that the firms that allocate a reasonable size of budgetary allocation for research & development spending tend to innovate more than others. Therefore, the private sector renewable energy development and demonstration budget (BRDD) plays an important role in environmental innovation and energy transition toward renewables (Lee and Min, 2015). A plethora of prior empirical studies have revealed that the BRDD can considerably enhance renewable energy consumption and reduce CO_2 emissions. For instance, the findings of Ahmed et al. (2021) reveal that the national budgetary allocation for renewable energy development and demonstration (BRDD) can considerably enhance environmental sustainability in the United States by reducing carbon dioxide emissions. Similarly, Ahmad et al. (2022a) conclude that BRDD can considerably improve environmental sustainability and reduce the ecological footprint in OECD countries from 1984 to 2018. The findings of these studies reveal that BRDD can considerably enhance environmental and ecological sustainability. However, these studies have not explained the mechanism through which it can enhance sustainability. In this context, the only viable channels to support the impacts of BRDD on the environment are environmental innovation and renewable energy transitions. However, this study has not found any empirical investigation concerning the impacts of BRDD on environmental innovation.

2.3. Fiscal decentralization

The regional authority which is also known as fiscal decentralization implies the devolution of decision-making power from the center to the regions. In OECD countries, policies are designed at both country and regional levels. Hence, both policy regimes act together and exert influence of different intensities. According to OECD (2020), the policies implemented for various regions can have a profound impact as compared with the impact of country-level policies because regional governments contribute more than 60 percent of total public investment and 69 percent of total government expenditures. Therefore, the regional-level policy can have a profound impact on environmental innovation. Recognizing the importance of regional authority, Hu et al. (2022) explore the influence of regional authority on energy transition in OECD countries. The findings uncover that regional authority has a profound positive impact on energy transition. It can be concluded from the findings that regional authority can influence the environmental innovation required for the energy transition. However, the prior literature has overlooked the impact of regional authority on environmental innovation. Therefore, this study incorporates regional authority in the model, which is expected to boost environmental innovative capacity of firms.

2.4. Financial development and globalization

Financial development and globalization can expand market size along with providing required finance, which in turn can expand economic activities and capacity to innovate. Baloch et al. (2021) concluded that financial development and globalization can promote environmental quality across the globe. Similarly, a plethora of empirical literature has examined the impact of financial development and globalization on renewable energy consumption and environmental quality (Ahmad et al., 2022b; Belaid et al., 2021; Dogan and Seker, 2016; Rasoulinezhad and Taghizadeh-Hesary, 2022). However, literature on the influence of financial development and globalization on environmental innovation is relatively scant. Among this, Ghisetti et al. (2017) concluded that a reduction in financial barriers can enhance the innovative potential of small and medium-sized manufacturing enterprises in Europe. Similarly, Baloch et al. (2021) investigated the nexus between financial development, globalization, energy innovation, economic growth, and pollution levels in OECD countries from 1990 to 2017 by using the Pool Mean Group model. The findings reveal that financial development enhances energy innovation and improves the quality of the environment, while globalization enhances greenhouse gas emissions. These above-discussed studies reveal that financial development and globalization can influence environmental innovation and greenhouse gas emissions.

3. Methodology

This section of the study discusses the model, data, and methods used to uncover the behavior of environmental innovation in OECD countries.

3.1. Model

To explore drivers of environmental innovation in OECD countries, this study constructed an eclectic model that augments the model of Shah et al (2022) with the inclusion of carbon price policy, budget for renewable energy development and demonstration, fiscal decentration, financial development, and economic globalization. The augmented version of the model is reported as follows:

$$LEINOV_{it} = +\beta_0 + \beta_1 ETAX_{it} + \beta_2 CPLCY_{it} + \beta_3 RAUT_{it} + \beta_4 BRDD_{it} + \beta_5 FDEV_{it} + \beta_6 GLOB_{it} + \varepsilon_{it} \quad (1)$$

Where β_0 is coefficient of intercept, $\beta_1 \cdots ..\beta_6$ are slope coefficients of environmental taxation, carbon pricing, regional authority, budget for renewable energy development, financial development, and globalization, while ε_{it} is the white noise error term. The detailed description of variables, source, and expected signs of explanatory variables are reported in Table 1.

A plethora of empirical studies have used patents of environment-related technologies as a proxy for environmental innovation (Iqbal et al., 2021; Saha et al., 2022). Therefore, this study used the log of patents related to environmental technology as the dependent variable. Each of the selected heterogeneous countries has a varying potential for environmental innovation; therefore, the quantile regression can provide efficient estimates. Moreover. Quantile plots in Fig. 3 reveal that our dependent variable also exhibits quantile distribution. This distributional plot uses panel quantile regression analysis to address this quantile asymmetric behavior. According to Irfan et al. (2022) and Saha et al. (2022), environmental taxation/finance is the most important determinant of environmental innovation. The increase in taxation can enhance the cost of carbon-intensive technologies and correspondingly upsurges the demand for carbon-efficient technologies, which in turn can enhance environmental innovations. Similarly, the increase in carbon taxation can boost demand and production of innovative carbon efficient technologies. This proposition is also validated by Porter (1991) hypothesis that urges for stringent environmental regulation to enhance green innovation and commercial competitiveness.

Moreover, besides these demand-side considerations, the innovative capacity of any firm or nation depends on budgetary allocations for research and development. Therefore, BRDD can enhance the innovative potential of firms engaged in the development of environment-friendly technologies. A plethora of empirical investigations has discovered a significant positive influence of BRDD on environmental sustainability and ecological footprint (Ahmed et al., 2021). However, the literature has not probed the impact of BRDD on environmental innovations. As BRDD can lead to enhance innovation related to green energy, a positive impact of BRDD is expected on environmental innovation. Furthermore, the prior empirical studies conclude that financial development and globalization can significantly influence carbon dioxide emissions and environmental sustainability. The prior empirical study of Ghisetti et al. (2017) reveals the positive impacts of financial development and globalization on environmental sustainability. Therefore, this study is also expecting positive impacts of financial development and globalization on environmental innovation.

3.2. Methods

This study examines the effect of environmental taxation, carbon pricing policy, budget for renewable energy development & demonstration, financial development, globalization, and regional authority on environmental innovation in 29 heterogenous OECD countries from 1990 to 2019. As discussed earlier, Fig. 3 reveals large heterogeneities in the quantile distribution of the dependent variable. Therefore, traditional linear panel regression can lead to biased estimates. Furthermore, the descriptive analysis of selected variables as reported in Table 2 reveals considerable variation across scale and location measures of standard deviation for many variables. The large regional disparities of standard deviations motivate us to use the advanced methods of movements in quantile regression (MMQR) proposed by Machado and Santos Silva (2019).

MMQR can provide efficient estimates by addressing spiral dependence among explanatory variables in the model. Moreover, this technique can also address cross-sectional heterogeneity and variations across time and space. The conditional quantile estimator $Q_y(\tau|X)$ of the locational-scale variant is reported as:

$$Y_{it} = a_i + X\beta + \sigma(\delta_i + Z'\gamma)U \quad (2)$$

Where $(a_i, \beta, \delta_i, \gamma)$ are unknown parameters, (Y_{it}) is the dependent variable; X reveals the vector of explanatory variables, β is the slope coefficient, whereas Z is a k-vector of known differentiable transformation (with probability 1) of the component of X with element 1, such as:

Table 1
Variables, description, source, and expectations.

Variables	Description	Source	Expectations
Environmental innovation (LEINOV)	The natural logarithmic value of total registered patents of environmental related technologies	(OECD, 2022)	
Environmental tax as a percentage of GDP (ETAX)	Total environmental tax revenue as a percentage of GDP	(OECD, 2022)	Positive
Carbon pricing policy (CPLCY)	Binary variable for the imposition of carbon pricing policy, valuing 1 from date of imposition, otherwise 0	(World Bank, 2022)	Positive
Budget for renewable energy development and demonstration (BRDD)	Renewable energy research development and demonstration budgets (RR&D) in million US dollars	(IEA, 2022)	Positive
Regional authority (RAUT)	Index for fiscal decentration	(Shair-Rosenfield et al., 2021) and (Hooghe et al., 2016)	Positive
Financial development (FDEV)	Financial Development Index	(IMF, 2022)	Positive
Economic globalization (GLOB)	Index of economic globalization	(Dahlberg et al., 2022; Dreher, 2006)	Positive

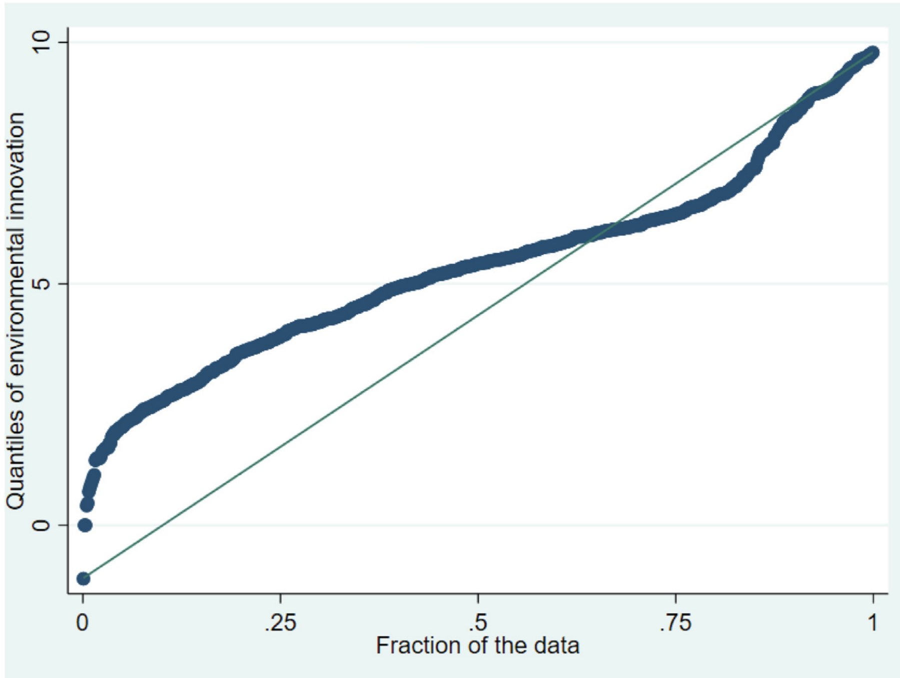

Fig. 3. Quantile plot of environmental innovation.

Table 2
Descriptive statistics of the variables.

Variable		Mean	Std. Dev.	Min	Max	Observations
LENOV	overall	5.334	2.072	−1.109	9.791	N = 725
	between		1.999	2.012	9.202	n = 29
	within		0.654	0.748	7.296	T = 25
ENTAX	overall	2.372	0.782	0.719	5.372	N = 737
	between		0.712	0.877	4.433	n = 29
	within		0.356	0.566	3.721	T-bar = 25.4138
CPPCY	overall	0.313	0.464	0.000	1.000	N = 754
	between		0.371	0.000	1.000	n = 29
	within		0.287	−0.456	1.275	T = 26
RAUT	overall	15.778	10.271	0.000	37.720	N = 725
	between		10.314	0.000	36.354	n = 29
	within		1.621	9.386	23.138	T = 25
BRDD	overall	3.122	2.135	−4.962	7.840	N = 606
	between		1.833	−0.703	6.879	n = 29
	within		1.094	−2.933	6.989	T-bar = 20.8966
FDEV	overall	0.631	0.203	0.094	1.000	N = 754
	between		0.192	0.227	0.937	n = 29
	within		0.074	0.334	0.788	T = 26
GLOB	overall	79.731	7.604	51.813	90.984	N = 725
	between		6.264	66.176	87.844	n = 29
	within		4.460	59.844	90.155	T = 25

Source: Authors' estimation. Note that varying observations of N reveal missing values in the data.

$Z = z_l(X), l = 1, \cdots\cdots, k$

While $\sigma(.)$ is a known function such that $\Pr\{\sigma(\delta_i + Z'\gamma) > 0\} = 1$, and U is the k-vector of an unobservable random variable that is independent of X with a density function that can be reported as:

$$E(U) = 0 \;\; and \;\; E(|\; U \;|) = 1 \tag{3}$$

The model reported in equation (2) represents a linear model where all unobservable heterogeneities come from the random variable, while the distribution of coefficients is assumed to differ only in scale and location. Therefore, it implies that,

$$Q_y(\tau|X) = \alpha + X'\beta + \sigma(\delta + Z'\gamma)q(\tau) \tag{4}$$

Where $q(\tau) = F_U^{-1}(\tau)$, with $\Pr(U < q(\tau)) = \tau$. When $\sigma(.)$ is identified function and Z = X then quantiles can be simplified into

$$Q_y(\tau, X) = \alpha + \delta q(\tau) + X'(\beta + \gamma q(\tau)) \tag{5}$$

In general terms, the marginal effect of the regressor X_l on τ – th quantile of Y can be represented as

$$\beta_l(\tau, X) = \beta_l + q(\tau)D^{\sigma}_{X_l} \tag{6}$$

Where $D^{\sigma}_{X_l} = \frac{\partial\sigma(\delta + Z'\gamma)}{\partial X'}$.

The parameters of interests can be identified by using equation (3) and a set of movement conditions that can be summarized as:

$$\mathrm{E}[\mathrm{RX}] = 0$$

$$E[X] = 0$$

$$E\left[(\mid R \mid -\sigma(\delta + Z'\gamma))D^{\sigma}_{\gamma}\right] = 0$$

$$E\left[(\mid R \mid -\sigma(\delta + Z'\gamma))D^{\sigma}_{\gamma}\right] = 0$$

$$E\left[I(R \leq q(\tau)\sigma(\delta + Z'\gamma)) - \tau\right] = 0$$

$$R = Y - (\alpha + X'\beta) = \sigma(\delta + Z'\gamma)U$$

$$D^{\sigma}_{\gamma} = \frac{\partial\sigma(\delta + Z'\gamma)}{\partial\gamma}$$

$$D^{\sigma}_{\delta} = \frac{\partial\sigma(\delta + Z'\sigma)}{\partial\delta}$$

The location-scale model specifies the scale function that can prove information and base identification concerning alternative sets of movements such as:

$$E[UX] = 0$$

$$E[U] = 0$$

$$E\left[(\mid U \mid -1)D^{\sigma}_{\gamma}\right] = 0$$

$$E\left[(\mid U \mid -1)D^{\sigma}_{\delta}\right] = 0$$

$$E[I(U \leq q(\tau)) - \tau] = 0$$

Where $U = \frac{Y - (\alpha + X'\beta)}{\sigma(\delta + Z'\gamma)}$.

The above-discussed conditions can form the basis of the estimation procedure that is termed Quantile via Movements (MMQREG)[1]. The major advantage of this technique over alternatives is that it can address non-linear behavior along with addressing endogeneity and spiral dependence issues.

4. Results and discussion

The panel data combines time-series observations of various cross-sections, and therefore, faces stationarity issues. Hence, this study proceeds with the exploration of unit root analysis. This study has collected data from heterogenous countries that can face cross-sectional dependence (CSD) problems and traditional unit root analysis ignores this issue. Therefore, this study first explores the CSD of selected variables by using the CD test of Chudik and Pesaran (2015). The disadvantage of the CD test is its sensitivity to the missing values. The results in Table 3 reveal that variables without missing values have cross-sectional dependency issues, which urges for the unit root analysis that could consider the CSD issue. Therefore, the cross-sectional Augmented Dickey-Fuller (CADF) panel unit test is employed to examine stationarity level and order of integration. The results in the second part of Table 3 reveal that most variables of the study are integrated at their level while missing values of BRDD make it difficult to estimate the stationarity level[2].

After exploring cross-sectional dependence and unit root features. The chosen variables were subjected to correlation analysis to examine the nature of spiral dependence among explanatory variables. Fig. 4 reveals a heatmap of the correlation matrix of the key variables. The heatmap figure reveals a mild spiral dependence among key variables. Fig. 5 represents the trends of variables by using the average for environmental technologies, carbon pricing policy, globalization index, financial development, regional authority, and aggregated environmental taxes as a percentage of GDP.

The descriptive statistics, quantile plots, unit root analysis, and heatmap of the correlation matrix validated the efficiency of Quantile via Movements estimation techniques proposed by Machado and Santos Silva (2019). This technique is superior to panel quantile regression as it can address variation across space and time along with the spiral dependency of dependent variables. The finding of scale and location also reveal a significant impact that validates the effectiveness of Quantile via Movement panel regression analysis. The estimated result of scale and location function and conditional quantiles-based estimates are reported in Table 4, while quantile plots are presented in Fig. 6.

The estimated results of the individual effect of the location function of the dependent variable (environmental innovation) reveal that all variables except economic globalization increase environmental innovation, while the scale function shows mixed effects concerning the dispersion of observed environmental innovation across the quantiles. The estimated results of Quantile via Movement reveal that taxation has a positive effect on environmental innovation in sampled countries in all quantiles. It indicates that environmental taxation can be an important policy variable to encourage the innovation capacity of sampled OECD countries. This finding is consistent with the prior empirical studies that found a significant positive influence of environmental taxation on the innovative capacity of environment-friendly technologies (Liao et al., 2018; Saha et al., 2022; Wang and Yu, 2021). Similarly, the second policy instrument adopted by OECD countries to encourage environmental innovation and renewable energy transition is the imposition of a carbon pricing policy that can also enhance environmental innovation by increasing the cost of carbon-intensive production technologies. The findings reveal that the imposition of carbon taxation increases environmental innovation from quantile 10 to quantile 60, while insignificant impacts are observed for high quantiles. Carbon pricing has been overlooked in the literature to explain environmental innovation; therefore, our novel findings urge for a moderate level of carbon pricing to enhance environmental innovation.

The regional authority of fiscal decentralization is the devolution of policymaking and implementation authority to regional governments. The findings of regional authority reveal a significant positive impact on environmental innovation. Moreover, the response is consistent and uniform throughout all quantile distributions. It implies that regional authority has a uniformly positive influence over environmental innovation in all quantiles. Although the literature on the effect of regional authority on environmental innovation is scarce, the findings of Hu et al. (2022) support our findings to some extent as they revealed the positive impact of fiscal decentralization on renewable energy transition in OECD countries. Moreover, according to OECD (2020), the regional authority is more effective for policy formulation and implementation as regional governments in OECD countries are responsible for more than 60 percent of total public investment and 69 percent of total government spending. Similarly, the budgets for renewable energy development and demonstration also show a uniformly positive impact throughout all quantiles. It indicates that the private sector budgets for renewable energy development can significantly enhance the overall environmental innovation of OECD countries. This positive impact is in line with the outcomes of prior studies regarding the adoption of renewable energy and the reduction of emissions as a result of increased BRDD (Ahmed et al., 2021).

[1] For more detailed description see (Machado and Santos Silva, 2019).

[2] This study has not used interpolation or extrapolation technique to fill the missing values of important variables such as BRDD, carbon pricing, and regional authority as it can reduce effectiveness of estimated results.

Table 3
Cross-sectional dependence & panel unit root test.

Cross-sectional dependency			CADF	
Variables	CD test	correlation	Z[t-bar] (Level)	Z[t-bar] (First Difference)
LEINOV	80.84***	0.802	−7.597***	−19.113***
ENTAX	17.842***	0.178	1.019	−14.618***
CPPCY	–	–	12.675	7.488
BRDD	–	–	NA	NA
RAUT	–	–	−2.431***	−15.445***
FDEV	65.76***	0.640	−3.076***	−18.372***
GLOB	96.05***	0.953	−2.537***	−15.514

Source: Author's estimation. Note that *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Notes: Under the null hypothesis of cross-section independence CD $\sim$ N (0,1).

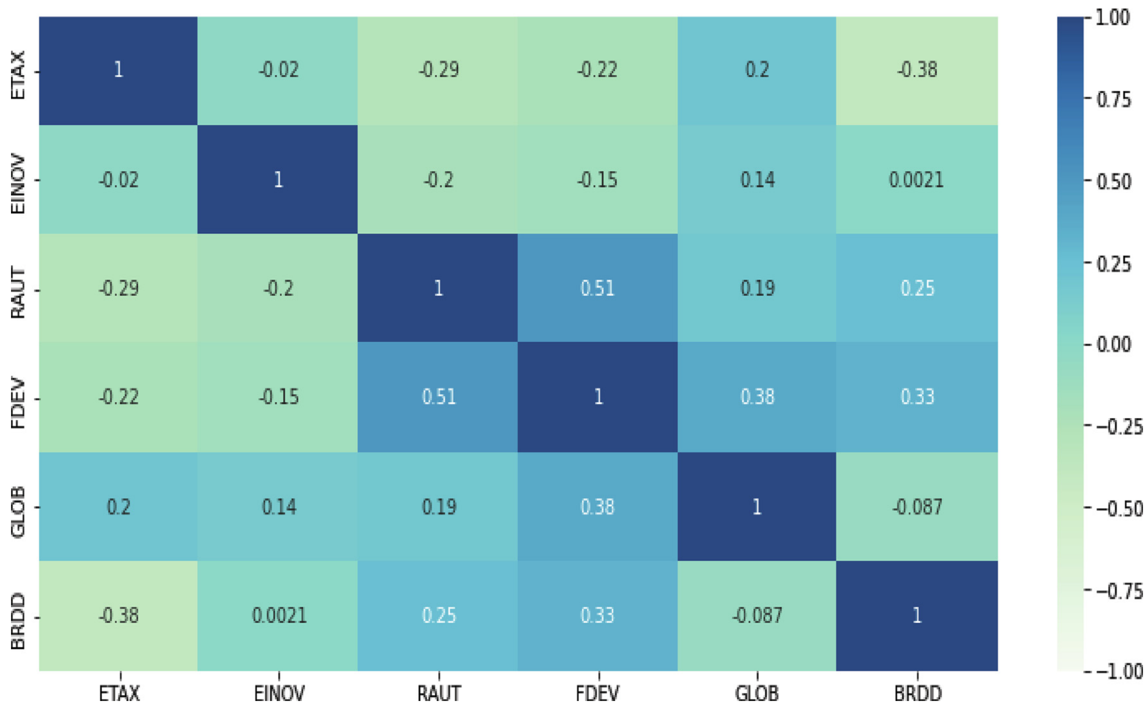

Fig. 4. Heatmap plot of the correlation matrix.

The computed outcome of financial development uncovers a significant positive impact of higher intensity on environmental innovation in all quantiles. This finding indicates that financial development provides the impetus (capital resources) required for environmental innovation in sampled OECD countries. Besides, it can also enable energy transition from fossil fuel to renewables by providing funds to acquire environment-friendly technologies. Moreover, Baloch et al. (2021) and Ahmed et al. (2022) consider financial development as a crucial driver to promote clean energy and environmental sustainability. The findings of globalization reveal a positive impact on environmental innovation in the lower quantiles, while at the higher quantiles, this effect transformed from positive to negative. This finding indicates that the early stages of globalization brought some capabilities and technologies to facilitate innovation; however, the expansion in FDI and trade has increased the flow of dirty technology to the OECD countries at higher quantiles. Thus, globalization is discouraging environmental preferences and environmental innovation, and the OECD nations tend to secure economic interests by disregarding innovation in environmental technologies. Ahmed et al (2021) supported our findings in the context of the USA. Also, this result is reasonable since prior empirical literature has reported that globalization increases carbon dioxide and other greenhouse gas emissions (Farooq et al., 2022; Ivanovski and Hailemariam, 2022; Tiba and Belaid, 2020; Wang et al., 2020). This finding urges efficient regularization of trade and FDI to encourage healthy competition by addressing environmental concerns. The findings of the intercept term indicate that in the absence of the above-discussed drivers, the environmental innovation should be negative in lower quantiles, such as quantile 10 to quantile 40 of environmental innovation. It implies that the above-discussed drivers provide foundations to countries in lower quantile to enhance environmental innovations. The graphical plot of quantile via movement results are also reported in Fig. 6.

Afterward, the model is tested by using the Driscoll-Kraay standard errors technique to find out the aggregate behavior of selected variables on environmental innovation. The basic rationale for using this technique lies in its benefits to address spiral dependence and provide unbiased estimates. The findings of Driscoll-Kraay in Table 5 validate the positive impact of environmental taxation, carbon pricing, regional authority, BRDD, and financial development on environmental innovation. However, the index

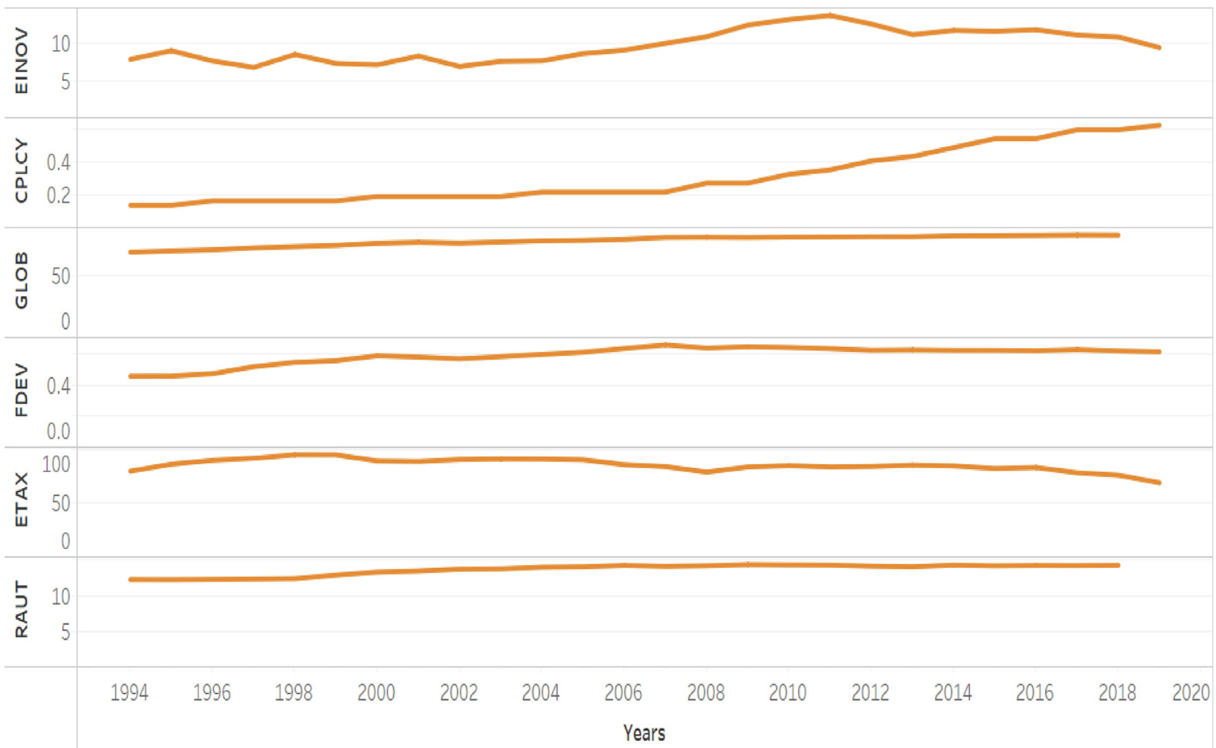

Fig. 5. Trends of variables.

Table 4
Result of Quantile via Movements.

	Dependent variable: $LEINOV_{it}$										
	Location	Scale	qtile-10	qtile-20	qtile-30	qtile-40	qtile-50	qtile-60	qtile-70	qtile-80	qtile-90
ENTAX	0.235***	0.0574	0.149*	0.174**	0.190***	0.212***	0.232***	0.251***	0.277***	0.298***	0.334***
	(0.0702)	(0.0423)	(0.0820)	(0.0732)	(0.0698)	(0.0681)	(0.0698)	(0.0743)	(0.0834)	(0.0934)	(0.113)
CPPCY	0.213*	−0.0631	0.308**	0.280**	0.262**	0.239**	0.217*	0.195*	0.168	0.144	0.104
	(0.111)	(0.0672)	(0.130)	(0.116)	(0.111)	(0.108)	(0.111)	(0.118)	(0.132)	(0.148)	(0.180)
RAUT	0.055***	−0.00043	0.056***	0.056***	0.0555***	0.0553***	0.0552***	0.0550***	0.0548***	0.0547***	0.0544***
	(0.00630)	(0.0038)	(0.00737)	(0.00657)	(0.00626)	(0.00611)	(0.00626)	(0.00666)	(0.00748)	(0.00839)	(0.0102)
BRDD	0.00338***	0.00028	0.00296***	0.00308***	0.00316***	0.00327***	0.00337***	0.00347***	0.00359***	0.00370***	0.00388***
	(0.000404)	(0.0002)	(0.000472)	(0.000421)	(0.000402)	(0.000392)	(0.000402)	(0.000428)	(0.000480)	(0.000538)	(0.000652)
FDEV	4.494***	1.451***	2.322***	2.970***	3.367***	3.916***	4.422***	4.916***	5.548***	6.097***	7.003***
	(0.380)	(0.229)	(0.437)	(0.393)	(0.382)	(0.379)	(0.385)	(0.412)	(0.458)	(0.500)	(0.622)
GLOB	−0.00368	−0.051***	0.0730***	0.0502***	0.0361***	0.0167	−0.00115	−0.0186	−0.041***	−0.060***	−0.092***
	(0.0124)	(0.00745)	(0.0141)	(0.0127)	(0.0124)	(0.0124)	(0.0126)	(0.0135)	(0.0149)	(0.0161)	(0.0203)
Constant	1.029	3.961***	−4.901***	−3.132***	−2.049**	−0.548	0.833	2.180**	3.906***	5.406***	7.879***
	(0.905)	(0.545)	(1.033)	(0.933)	(0.912)	(0.910)	(0.923)	(0.990)	(1.095)	(1.183)	(1.488)
Observations	585	585	585	585	585	585	585	585	585	585	585

Source: Authors' estimation. Note Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

of economic globalization reveals an insignificant negative impact. These findings are consistent with the results obtained from Quantile via movements.

5. Concluding remarks

By far, the dynamics of the drivers of environmental innovation in the OECD countries have been discussed. The study outcome has provided significant insights for policymaking. A baseline policy framework is designed based on the outcomes.

Promoting environmental innovation by reorienting its drivers requires a phase-wise approach, as the drivers might need to be prioritized in accordance with the criticality of their impacts. To start with, promoting environmental innovation requires a proper financialization channel. Policymakers might need to promote environmental innovation by enhancing its demand and reorienting the financing mechanism. Creating a carbon footprint-linked differential interest rate mechanism might discourage the usage of fossil fuel-based solutions and encourage achieving energy efficiency through promoting cleaner energy solutions. The cleaner firms might also be endowed with interest rates and tax holidays. Shifting away from fossil fuel sources and promoting cleaner energy solutions will require environmental innovations. Hence, this initiative will possibly create a demand for environmental innovations within the nation. At the same time, introducing the Pigouvian tax mechanism for polluting firms will also encourage the use of environmental innovation with a view to achieve environmental fortification. This mechanism will not only help in achieving improvement in environmental quality through environmental innovation but also will help in earning interest and tax

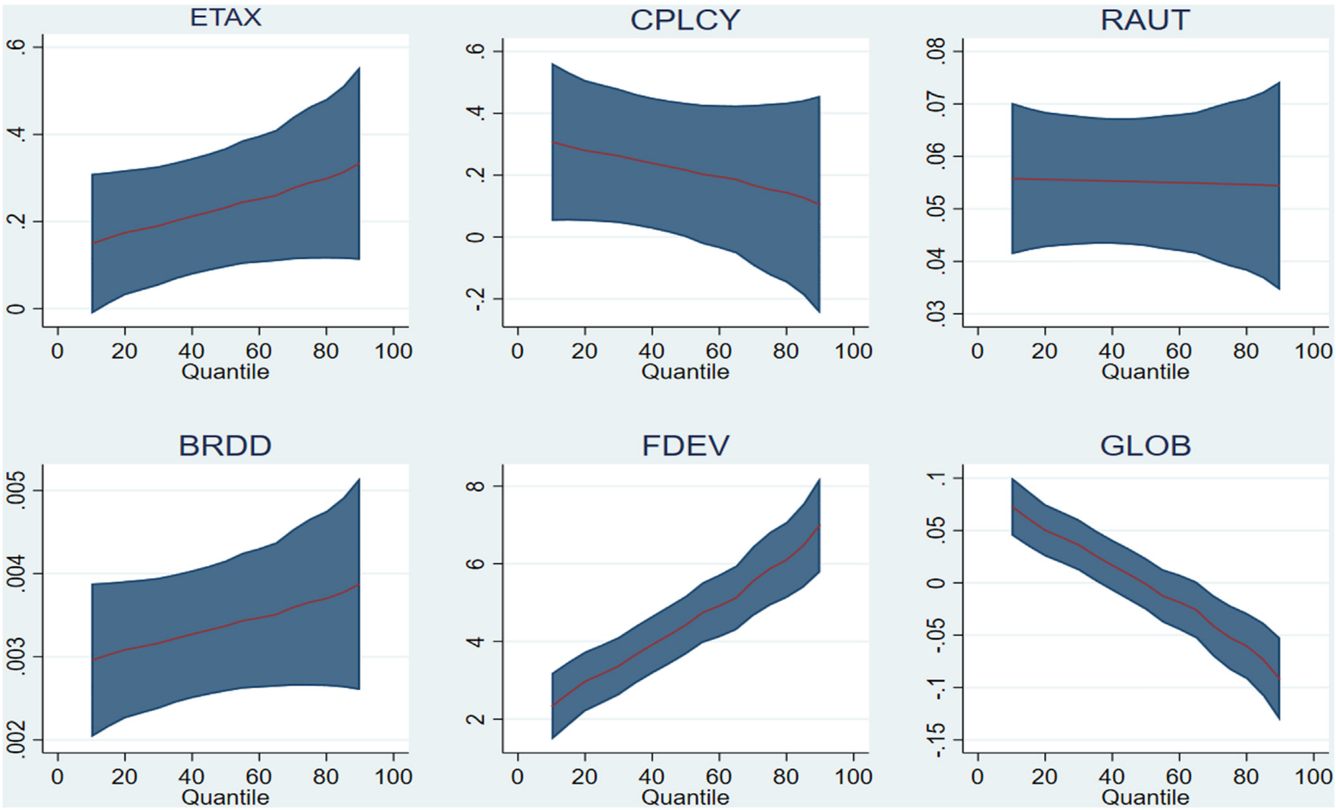

Fig. 6. Quantile via Movements plots.

Table 5
Results of Driscoll-Kraay standard errors.

	Dependent variable:$LEINOV_{it}$			
	Coef.	Drisc/Karry Std. Error	t. stat.	prob.
ENTAX	0.235	0.0802	2.92	0.007
CPPCY	0.213	0.0990	2.16	0.041
BRDD	0.0034	0.0006	5.66	0.000
RAUT	0.0551	0.0005	10.83	0.000
FDEV	4.4939	0.4785	9.39	0.000
GLOB	−0.0037	0.0144	−0.26	0.800
CONS	1.0286	0.8726	1.18	0.250
Number of observations			585	
Number of groups			29	
F-statistics (prob)			417.73(0.000)	
R-squared			0.61	
Root MSE			1.196	

Source: Author's calculation. Note that z score values are presented inside () and *** p < 0.01, ** p < 0.05, * p < 0.1.

revenues via the continued usage of fossil fuel sources. These revenues will help in building the further phases of the policy framework.

Operationalization of the first phase of the policy framework will prepare a base for the second phase of the framework. The revenue earned in the first phase should be used as a measure to subsidize the environmental innovation solutions. The high implementation cost of these solutions might impede a number of players in the first phase. Subsidizing these solutions will reduce the entry to the barrier in this market, and these solutions will be able to achieve economies of scale. This will in turn reduce the cost of these solutions. Cost reduction of these solutions will help the producers in penetrating the household sector. This will help them in making these solutions available at the grassroots level. Moreover, upon completion of the tax and interest rate holidays, the revenue earned from these firms can be utilized to boost research and development in these countries. This step is necessary to discover alternate energy solutions and more energy-efficient solutions. Continuing this research requires a constant source of funding, which can be achieved from tax revenue and interest income.

Once the second phase is operational, the dependence of these countries on imported fossil fuel solutions will be reduced. So, this phase of the policy framework should be aimed at developing the domestic capacity to innovate and restricting the import of technological solutions. Hence, policymakers need to impose import-substitution policies for restricting environmental technologies. At the same time, strict import substitution should be imposed for restricting the import of fossil fuels, polluting technologies, or any work-in-progress with a high carbon footprint. It will help in internalizing the negative environmental externalities of globalization and international trade channels. Moreover, restricting the international flow of technological solutions will create a void within the nation. It will allow domestic researchers and producers to develop the solutions domestically. It will not only help in saving the trade balance of the nation but also will help in creating green jobs in an organic way. The environmental regulations should be made stringent. It will help in safeguarding the rights of public goods and can diminish the unwarranted consumption of natural resources. The regional authorities should be empowered to realize this process.

Development of the policy framework will help in developing the domestic capacity to innovate and build an environment of research and development toward the discovery of alternate energy resources within the nation. The bottom line of this policy achievement is the attainment of the SDG 9 objectives. This accomplishment will help in making energy solutions cleaner and more affordable, and the energy security issue in these countries can be addressed. It will help in achieving the SDG 7 objectives. Cleaner energy solutions will help in environmental fortification by reducing the level of ambient air pollution. This will help in achieving the SDG 13 objectives.

The policy framework is developed by considering the aspects of financialization and regulatory authorities responsible for promoting environmental innovation. This focus might seemingly narrow down the scope of the policy framework. However, the phase-wise design of the policy framework might provide it with a sense of generalizability, which makes this policy framework a benchmark policy design for other countries. The policy framework is flexible, and hence, it can be tailored according to contextual specificities. Despite the said limitation, it defines the contribution of the study. Future studies on this aspect can be carried out by incorporating the moderation of the legislative frameworks and geopolitical shocks in the policy framework.

CRediT authorship contribution statement

Shujaat Abbas: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft. **Zahoor Ahmed:** Investigation, Writing – original draft, Writing – review & editing. **Avik Sinha:** Investigation, Writing – original draft, Writing – review & editing. **Oleg Mariev:** Writing – original draft, Writing – review & editing. **Faisal Mahmood:** Writing – review & editing, Visualization.

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.

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