

Do Competitive Export Markets Lower Climate Risk? The Role of Eco-Entrepreneurship and Renewables

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Abstract

The United Nations' Sustainable Development Goal 13 emphasizes the urgent need to mitigate climate-related risk to ensure ecological sustainability. Against this backdrop, the present study examines how export market structure and environmental entrepreneurship affect environmental risk by applying the method of moments quantile regression (MMQR) approach. The findings show that export market structure has a significant positive effect on environmental risk across most quantiles. Because the export market structure variable is measured using the Herfindahl-Hirschman Index (HHI), this result indicates that greater export market concentration increases environmental risk, whereas a more competitive export market structure mitigates it. Environmental entrepreneurship has a significant negative effect on environmental risk across quantiles, underscoring the importance of renewable energy sources in reducing environmental risk. Overall, the results reveal substantial heterogeneity across the conditional distribution of environmental risk. The Dumitrescu-Hurlin test indicates bidirectional causality between environmental risk and the explanatory variables included in the causality model. The FMOLS and Driscoll-Kraay standard error estimates confirm the robustness of the main findings. Finally, the empirical results offer important policy implications for stakeholders seeking to reduce environmental risk.

Keywords: Export Market Structure, Environmental Entrepreneurship, Environmental Risk, SDG 13, MMQR, BRICS+

JEL Classification: F18, Q56, L26, C23, O44

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1 INTRODUCTION

The United Nations (UN) established Sustainable Development Goal (SDG) 13 for 2030 to promote environmental sustainability by addressing climate change concerns. Environmental risk is the possibility of adverse environmental events arising from natural processes, human actions, or a combination of both (Ellis, Figueredo, Brumbach, & Schlomer, 2009). It encompasses several hazards and challenges that may negatively affect the natural environment, ecosystems, human health, and society (Aven, 2020; Ellis et al., 2009; Vural, 2020). Environmental risk evaluation seeks to identify, analyze, and mitigate these risks to reduce their adverse impacts (Aven, 2020; Ellis et al., 2009; Vural, 2020). Human activities contribute to climate change by producing carbon dioxide (CO₂) and other greenhouse gases (GHGs), thereby intensifying environmental risks (Aven, 2020). In 2016, CO₂ emissions accounted for nearly 74.4% of the world's greenhouse gas emissions. CO₂ emissions could also increase the Earth's temperature by 5 to 6 degrees Celsius in the coming decades (Tollefson, 2020).

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Therefore, this research primarily focuses on CO₂ emissions to estimate the environmental risk of BRICS+ countries.

The newly expanded economic bloc, designated as BRICS+ (Brazil, Russia, India, China, South Africa, Egypt, Ethiopia, Iran, Saudi Arabia, and the United Arab Emirates), accounts for nearly 45% of the global population (Ross, 2023). From a trade perspective, the expanded BRICS+ alliance accounts for 43% of global oil production and extends its geostrategic influence in the Middle East by including the UAE, Iran, and Saudi Arabia (Ross, 2023). The BRICS+ countries account for around 25% of global exports, whereas Brazil, Russia, India, and China hold 72.5% of the world's rare earth resources (Visual Capitalist, 2021; Ross, 2023). Nevertheless, these countries have also been identified as significant contributors to environmental risk. The economies of India, China, and Brazil are linked to the production of industrialized goods. In contrast, Russia and South Africa are recognized for their NTR-based economies, with NTR extraction significantly contributing to CO₂ emissions (Q. Shao, Wang, Zhou, & Balogh, 2019; H. Wei, Yue, & Khan, 2024). Environmental pollution contributes to cardiovascular diseases, rendering multiple cities in China and India uninhabitable due to perilous CO₂ emissions (Kumar, Sasidharan, & Bagepally, 2023). Moreover, the Gulf nations' substantial dependence on oil consumption escalates CO₂ emissions and adversely affects the environment (Salem, Pudza, & Yihdego, 2023). The BRICS+ countries constitute a crucial domain of study due to their substantial contributions to global trade, population, and natural resource reserves. Initiatives within the BRICS+ countries can help achieve the United Nations' Sustainable Development Goals (SDGs). Hence, this paper explores the contribution of export market structure and environmental entrepreneurship in mitigating environmental risk among the BRICS+ countries. Figure 1 displays CO₂ emissions in BRICS+ countries from 1998 to 2022.

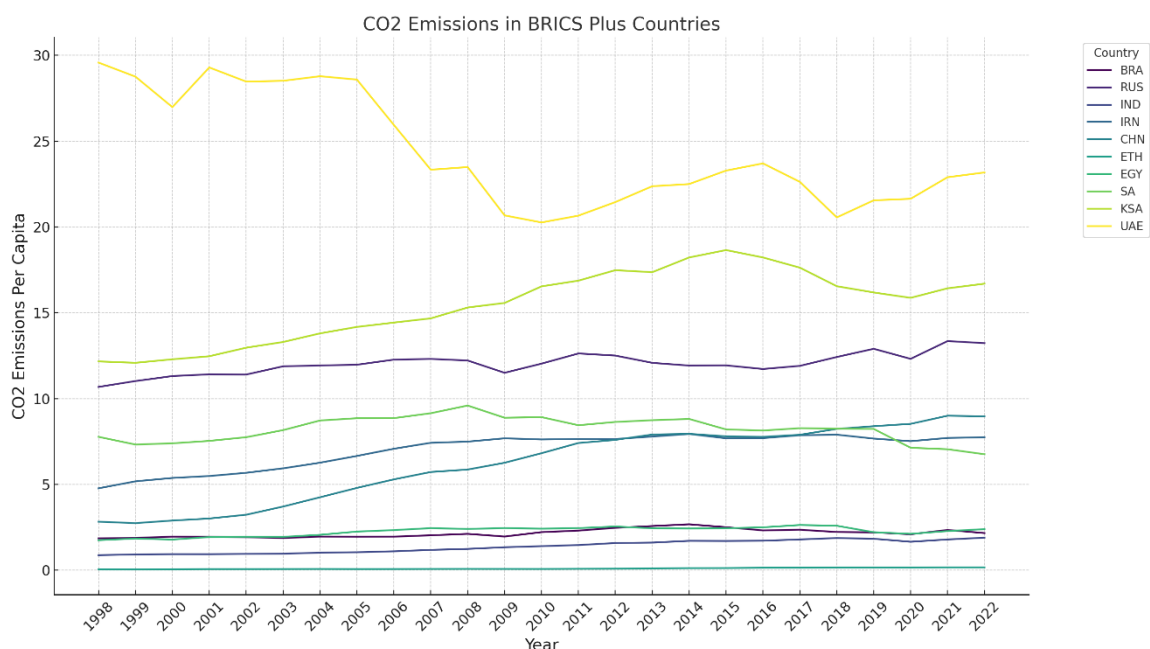


Fig. 1 – CO₂ emissions in BRICS+ countries. Source: own research

The market structure demonstrates the extent of concentration or competition in marketplaces (Xiang, Cui, & Bi, 2023). In particular, export market structure represents the extent of

competition or concentration in a country's export markets. The theoretical lens of this research for export market structure is the Herfindahl-Hirschman Index (HHI) based on mirror export data developed by the World Bank (World Bank, 2024). A country's concentrated or competitive export market structure can affect economic and environmental outcomes. Several studies have shown that the level of market competition or concentration can affect environmental outcomes through research and development, investment efficiency, technological advancement, fixed-asset investment, infrastructure, and manufacturing capacity development (Gao, Ru, Townsend, & Yang, 2019; Guariglia & Yang, 2016; Liu & Li, 2020; Naeem & Li, 2019; Xiang et al., 2023). However, export market structure can affect environmental risk in either direction. On the one hand, expanding trade activity and rising energy consumption can increase CO₂ emissions (Le, Chang, & Park, 2016; Rauf, Zhang, Li, & Amin, 2018). On the other hand, Sun, Enna, et al. (2020) show that expanding trade markets can help reduce CO₂ emissions in the long run.

In addition to export market structure, environmental entrepreneurship has become a prominent area of research and a promising avenue for combating climate change and global warming (Sun, Pofoura, Mensah, Li, & Mohsin, 2020) and achieving sustainable economic development (X. Wei, Ren, Ullah, & Bozkurt, 2023). The literature demonstrates that entrepreneurial initiatives promote green infrastructure and support the green transition in the economy (Hu, Wang, & Huang, 2021; W. Li & Ullah, 2022; Ying, Zhang, Zhang, & Bilan, 2022). Entrepreneurial efforts also encourage organizations to adopt clean and green technologies that minimize environmental strain while supporting economic development (Ullah, Ozturk, Majeed, & Ahmad, 2021; W. Li & Ullah, 2022). Despite this discussion, the literature cannot provide substantial evidence that explicitly analyzes the link between export market structure (competitive versus concentrated) and environmental risk. Furthermore, the literature lacks research that explicitly investigates the influence of environmental entrepreneurship on environmental risk. Nevertheless, these research gaps are critical and call for immediate investigation to identify and effectively manage environmental risks, which are of paramount importance in the fight against climate change under SDG 13.

Drawing on the theoretical grounds above, this research makes the following novel contribution to the standing environmental risk literature. First, unlike prior studies, which mainly focused on traditional investigations, such as trade openness and environmental sustainability (Wang, Hu, & Li, 2024), export diversification and environmental sustainability (Shi, Visas, Ul-Haq, Abbas, & Khanum, 2023), trade diversification and environmental sustainability (Wang, Zhang, & Li, 2024), this is pioneering research evaluating the relationship between export market structure (concentrated/competitive) and environmental risk. This research incorporated the market concentration index, computed using mirror export data from the World Bank, to evaluate, for the first time, the potential influence of export market structure on environmental risk. Second, a limited body of research has examined the link between environmental entrepreneurship and pollution (Sun, Pofoura, et al., 2020) and sustainable development (X. Wei et al., 2023). However, to the author's knowledge, this is the first effort to specifically evaluate the influence of environmental entrepreneurship on environmental risk. Notably, this analysis transcends prior studies by employing diversified proxies to approximate environmental entrepreneurship, such as renewable energy consumption as a percentage of

total energy consumption and renewable electricity production as a percentage of total electricity production. Third, this research is the first to analyze the influence of export market structure and environmental entrepreneurship on environmental risk in BRICS+ countries. Fourth, this study utilized a novel method-of-moments quantile regression (MMQR) with fixed effects to better understand the relationships among quantiles. This technique also links heterogeneous components at various levels within the distribution range of conditional quantiles. This approach offers more robust findings than standard mean regression. Fifthly, SDG 13, as part of the UN 2030 Agenda for Sustainable Development, is focused on “Climate Action.” This objective covers the critical global problem of climate change and its wide-ranging repercussions. It provided a massive challenge to emerging economies and is particularly tied to BRICS+ countries. Nevertheless, this analysis articulates suitable policy recommendations for BRICS+ countries that are consistent with the UN SDGs.

The succeeding sections are organized as follows: The second section contains a complete evaluation of the attributed scholarly literature. Section 3 discusses the methodology and resources utilized to accomplish the study. Section 4 presents the research’s empirical findings and analysis, while Section 5 presents the study's conclusions and policy recommendations.

2 THEORETICAL BACKGROUND

2.1 THEORETICAL MOTIVATION

This study adopted the market power hypothesis to establish rigorous theoretical grounds for investigating the link between export market structure and environmental risk within the BRICS+ framework. The advocates of the market power hypothesis exhibit two different perspectives on how it affects environmental outcomes. Increasing market competition eventually reduces monopolistic power (Amore, Schneider, & Žaldokas, 2013; Love & Martínez Pería, 2015). The competitive market structure further drives businesses to differentiate themselves through innovation and to enhance their research and development efforts to adopt sophisticated, sustainable technologies. In competitive marketplaces, businesses are oriented towards resource-efficient processes to reduce production costs. Several studies argued that fierce competition would ultimately raise investment efficiency, stimulate research and development, and accelerate technological innovation. (Guariglia & Yang, 2016; Hall et al., 2016; Liu & Li, 2020; Naeem & Li, 2019). On the flip side, businesses spend excessively on acquiring fixed assets, such as developing infrastructure and expanding industrial capacity and equipment, to grow their market share in the competitive market structure. As a result, it puts more strain on natural resources and energy consumption. Moreover, businesses prioritize short-term economic targets under competitive pressure and forgo long-term investments in sustainable practices. Investment in fixed assets increases energy consumption and boosts CO₂ emissions (Abbasi & Riaz, 2016; Al-Mulali, Solarin, & Ozturk, 2016). Gao et al. (2019) acknowledged the early claims that increased competition in financial markets stimulates investment in fixed assets to meet targeted productivity and profitability levels. Xiang et al. (2023) state that a competitive market structure could stimulate technological improvement to

compress CO₂ emissions at one end and boost investments in fixed assets to increase carbon emissions on the other end.

Secondly, stakeholder theory (Clarkson, 1995) provides a solid theoretical base that elucidates the specific linkages between export market structure, environmental entrepreneurship, and environmental risk. Advocates of stakeholder theory argue that heavily polluting businesses should prioritize the interests of all stakeholders - including shareholders, society, consumers, governments, and employees - instead of focusing solely on increasing shareholder wealth (Qian & Yu, 2024). Stakeholders and governmental authorities are considerably concerned with reducing the ecological damage triggered by CO₂ emissions (Esmaeil, Rjoub, & Wong, 2020). The immense accumulation of CO₂ emissions in the atmosphere contributes to cardiovascular illnesses, and numerous cities in BRICS+ countries are deemed dangerous for human habitation (Kumar et al., 2023). The present imperative is to deploy measures that minimize CO₂ emissions. In line with stakeholder theory, market structure (competitive or concentrated) is an integral element affecting CO₂ emissions (Chen, Xu, & Anwar, 2024; Zhu, Ding, & Du, 2024). Moreover, environmental entrepreneurship could potentially reduce climate change concerns (Nadeem Iqbal, Khan, Gill, & Abbas, 2020) while promoting sustainable green development (X. Wei et al., 2023). Thus, the preceding discussion underscores the relevance of export market structure and environmental entrepreneurship as feasible solutions to combat climate change and mitigate environmental risks while safeguarding the interests of all stakeholders.

2.2 EXPORT MARKET STRUCTURE AND ENVIRONMENTAL RISK

The correlation between market structure (competition or concentration) and environmental risk in export-driven countries has garnered significant interest. The Herfindahl-Hirschman Index (HHI) is primarily used in academic literature to assess market concentration (Xiang et al., 2023). Trade operations may substantially affect environmental outcomes, particularly CO₂ emissions. Nonetheless, past studies present conflicting findings on whether export activities intensify or reduce environmental pressure across countries. Most of the literature focuses on traditional trade indicators. For example, Le, Chang, and Park (2016) show that trade openness in a worldwide sample of 98 nations increases CO₂ emissions. Rauf, Zhang, Li, and Amin (2018) investigated the correlation between trade openness, energy consumption, and CO₂ emissions using ARDL bounds testing on Chinese time-series data from 1968 to 2016, and they determined that trade openness increases CO₂ emissions and can lead to environmental deterioration. Using the AMG estimator, Najaf Iqbal et al. (2021) examined the relationship between export diversification and environmental sustainability in 37 OECD nations and found that diversifying a nation's exports across markets increases CO₂ emissions and undermines environmental sustainability. Likewise, M. Li, Ahmad, Fareed, Hassan, and Kirikkaleli (2021) reported similar conclusions for the Chinese economy. This line of evidence suggests that a concentrated export market structure could, in some settings, reduce environmental risk by limiting the scale of carbon-intensive export expansion. Conversely, Shahzad, Ferraz, Doğan, and do Nascimento Rebelatto (2020) examined the nexus between export diversification and CO₂ emissions across 63 developing and developed nations from 1971 to 2014. Their system-GMM estimates showed that diversity in export markets increases environmental sustainability by reducing CO₂ emissions. Sun, Enna, et al. (2020) also reported that expanding trade markets

helps minimize CO₂ emissions in Sub-Saharan African nations in the long run. According to H. Khan, Liu, and Khan (2022), trade openness, institutional quality, and environmental innovation reduce CO₂ emissions and improve environmental sustainability in 176 nations. For Pakistan, Huo, Ullah, Zulfiqar, Parveen, and Kibria (2022) studied the relationship between trade openness, financial development, foreign direct investment, and environmental sustainability from 1996 to 2019. By applying the autoregressive distributed lag (ARDL) model, they determined that foreign direct investment, trade openness, and financial development contribute to increased environmental sustainability. Taken together, this empirical evidence suggests that a less concentrated and more competitive export market structure could help minimize environmental risk by lowering CO₂ emissions.

Recent investigations in the Chinese banking sector have produced mixed results concerning banking competition and the CO₂ emissions nexus. Xiang et al. (2023) evaluated the link between banking competition, government intervention, and CO₂ emissions from 2000 to 2017. By applying the 2SLS estimation approach, they asserted that higher banking competition raises CO₂ emissions and that government intervention further magnifies this carbon-raising effect. Zhu et al. (2024) reported similar evidence and confirmed a positive association between banking competition and CO₂ emissions. However, Chen et al. (2024) found the opposite result, showing that banking competition decreases CO₂ emissions and enhances environmental sustainability. In short, the discussion above highlights the relevance of market structure for addressing the hazardous problem of environmental risk. Therefore, we propose the following hypothesis:

H1: Export market structure (concentration/competition) significantly affects the environmental risk in BRICS+ countries.

2.3 ENVIRONMENTAL ENTREPRENEURSHIP AND ENVIRONMENTAL RISK

Early work on ecopreneuring can be traced to Bennett (1991). Several studies have highlighted renewable energy sources as fundamental components of environmental entrepreneurship (Dean & McMullen, 2007; Gast, Gundolf, & Cesinger, 2017). In addressing the UN SDGs, environmental entrepreneurship has emerged as a promising approach to combating climate change and environmental degradation in recent years. The perspective of conventional entrepreneurs has been evolving towards environment-related entrepreneurial operations to analyze their potential impact on environmental outcomes (Gu & Zheng, 2021). The relevance of environmental entrepreneurship has underscored the importance of conserving natural resources and promoting ecological sustainability. Sun, Pofoura, et al. (2020) evaluated the environmental entrepreneurship-sustainable development nexus using a sample of 35 Sub-Saharan African nations from 2000 to 2014. They used Pooled Mean Group estimators in Autoregressive Distributed Lag estimation and found that environmental entrepreneurship helps alleviate environmental degradation and supports sustainable development. For Pakistan, Nadeem Iqbal et al. (2020) observed that sustainable entrepreneurial activities help to minimize environmental pollution. Entrepreneurial activities that use renewable energy outcomes could constitute an effective gateway to mitigating climate change risk. According to S. Khan, Murshed, Ozturk, and Khudoykulov (2022), the environmental sustainability of the next eleven

countries will be enhanced over the long term by electricity generated from renewable sources. Similarly, Riti, Riti, and Oji-Okoro (2022) stated that renewable energy consumption promotes the preservation of sound economic and ecological standards. In their work, Jin and Huang (2023) examined the potential influence of industrialization and renewable energy consumption on environmental sustainability in South Africa, using the NARDL estimation approach from 1990 to 2019. They examined environmental sustainability using the load capacity factor and determined that electricity from renewable sources helps safeguard the environment from deterioration. From Asian economies, X. Wei et al. (2023) investigated the relationship between environmental entrepreneurship and sustainable green development from 1990 to 2019. They employed two distinct proxies to measure environmental entrepreneurship: energy production from renewables and nuclear and renewable energy. By employing ARDL-PGM, they discovered that green economic growth is significantly facilitated by environmental entrepreneurship. However, environmental entrepreneurship is measured with various factors in the literature, like Renewable energy share in % (Nadeem Iqbal et al., 2020; Sun, Pofoura, et al., 2020), and renewable energy production & renewable electricity production (X. Wei et al., 2023). Nonetheless, environmental entrepreneurship primarily focuses on renewable energy sources, which could help minimize CO₂ emissions and mitigate environmental risks. Thus, we propose the following hypothesis in light of the available literature:

H2: Environmental entrepreneurship significantly mitigates environmental risk in BRICS+ countries.

2.4 SUMMARY OF THE LITERATURE GAP

According to the literature review above, three frameworks of environmental work can be found in the entire literature: 1) environmental pollution, 2) environmental sustainability, and 3) environmental deterioration. This research, meanwhile, will be groundbreaking and offer a novel lens on environmental risk. Regarding export market structure, earlier studies have traditionally investigated export diversification, trade openness, trade diversification, and the nexus between environmental outcomes and these variables, with comparatively little research using banking-sector data that connects with the current study. Additionally, prior studies have examined the effects of environmental entrepreneurship on sustainable development, green economic growth, and environmental pollution, while largely neglecting environmental risk. However, this research will be pioneering and offer a new horizon for the study of export market structure, environmental entrepreneurship, and the environmental risk nexus in BRICS+ countries. Moreover, BRICS+ countries are burdened with the obligation to align their development goals with the UN-established SDGs. SDG 13, particularly regarding climate action, underscores the importance of addressing climate change and its impacts. According to the present study, integrating environmental entrepreneurship and export market structure in BRICS+ countries is key to achieving this goal.

3 RESEARCH OBJECTIVE, METHODOLOGY AND DATA

3.1 DATA AND MATERIAL

This research focuses on the relationship between export market structure, environmental entrepreneurship, and environmental risk. The BRICS+ economies (Brazil, Russia, India, China, South Africa, Egypt, Ethiopia, Iran, United Arab Emirates, and Saudi Arabia) are included in this investigation spanning from 1998 to 2022. Apart from export market structure (HHI), this study's variables were adjusted by computing the natural logarithm. Since these variables are measured differently, taking natural logarithms makes them more homogeneous and ensures the reliability of the outputs (H. Wei et al., 2024). Nonetheless, some key variables may contain negative or zero values, which were adjusted through the following standardized empirical procedure. Notably, we have normalized the variables before the formal logarithmic transformation to preserve relative variation in the data series. The dependent variable in the study is environmental risk; the independent variables are export market structure and environmental entrepreneurship. The control variables include inflation, natural resources rent, research and development (R&D), and financial development. The study utilized a comprehensive dataset; however, a few observations were missing. Therefore, this study used a mean-filling methodology to supplement any missing observations (P.-C. Jiang, Feng, & Yang, 2022). This method is especially appropriate and plausible for quantile-based investigation (Asif, Gao, & Zafar, 2025; Liya, Su, Baz, & Xue, 2026). However, to ensure the robustness of the results, we have used linear interpolation to supplement missing values, thereby maintaining the consistency and accuracy of the outcomes.

Table 1 explains the selected variables, operational definitions, and their codes. Table 2 provides the descriptive statistics for the variables included in the study's model. Nevertheless, the Jarque-Bera statistical test provides strong evidence to reject the null hypothesis of normality, indicating that the unconditional distributions of all variables deviate markedly from the normal pattern. The varied results provided by the descriptive statistics reinforce the justification for adopting this study's "method of moments quantile regression" (MMQR) strategy.

Tab. 1 – Variable explanation. Source: own research

Variables	Codes	Operational Definition	Ref.	Source
Environmental risk	ERISK	Environmental risk refers to CO ₂ -emission-based environmental risk. The study has used the well-acknowledged Z-score of CO ₂ emissions per capita as a credible proxy for estimating CO ₂ emissions in relation to environmental risk. Several recent studies have found that CO ₂ emissions are among the biggest environmental risks associated with climate change, ecological stress, and environmental damage. Nonetheless, the greater CO ₂ -related environmental risk is associated with higher CO ₂ emissions, which indicate greater climate vulnerability. Moreover, to keep it simple, we have operationalized it as environmental risk, consistent with recent studies.	(Kaewsaeng-on & Mehmood, 2024; X. Shao, Hu, Yunis, & Hao, 2026)	WDI

Variables	Codes	Operational Definition	Ref.	Source
Export market structure	MKTS	Export market structure is conceptualized through the “Herfindahl-Hirschman Market Concentration Index (HHI) based on Mirrored Export, developed by the World Bank. Notably, higher HHI values indicate a more concentrated export market structure, while lower values indicate a highly competitive one. Nonetheless, the study has used the HHI index without any formal transformation.	(World Bank, 2024)	WB
Environmental entrepreneurship	EENT	The study conceptualized environmental entrepreneurship using two well-established macro-level proxies: renewable electricity production as a % of total electricity production (EENT) and renewable energy consumption as a % of total energy consumption (RE). Several recent cross-country investigations indicate that, at the national level, green entrepreneurial initiatives are largely driven by the growth of renewable energy industries. Nonetheless, we have applied two distinct proxies to examine the impact of environmental entrepreneurship on environmental risk.	(X. Wei et al., 2023)	WDI
	RE		(Sun, Pofoura, et al., 2020)	WDI
Inflation	INFL	It represents the rate of inflation in a country.	(Cicchello, Cotugno, & Foroni, 2023)	WDI
Natural resources Rent	NNR	The ratio of natural resource rent to GDP.	(Udeagha & Ngepah, 2023)	WDI
Research & development	R&D	It represents research and development expenditure as a percentage of GDP	(Y. Jiang, Hossain, Khan, Chen, & Badeeb, 2024)	WDI
Financial development	FD	It represents domestic credit provided by banks to the private sector as a percentage of GDP.	(X. Wei et al., 2023)	WDI
Note: WB denotes "World Bank" and WDI denotes "World Development Indicators."				

3.2 EMPIRICAL MODEL

Following (Jahanger et al., 2024), this study designed equation (1) to evaluate the model empirically

$$ERISK_{i,t} = f (MKTS, EE, INFL, NNR, R\&D, FD) \quad (1)$$

ERISK, MKTS, EE, INFL, NNR, R&D, and FD represent environmental risk, export market structure, environmental entrepreneurship, inflation, natural resource rent, research and development, and financial development. The model's estimation format is given in equation (2).

$$ERISK_{i,t} = \omega_0 + \omega_1 MKTS_{i,t} + \omega_1 EE_{i,t} + \omega_1 INFL_{i,t} + \omega_1 NNR_{i,t} + \omega_1 R\&D_{i,t} + \omega_1 FD_{i,t} + \varepsilon_{i,t} \quad (2)$$

In this equation, i denotes the cross-sectional unit, t denotes time, and $\varepsilon_{i,t}$ represents the error term.

3.3 EMPIRICAL STRATEGY

The following section comprehensively explains the empirical strategy and econometric model used in this study. Figure 2 depicts a flow chart of the empirical strategy.

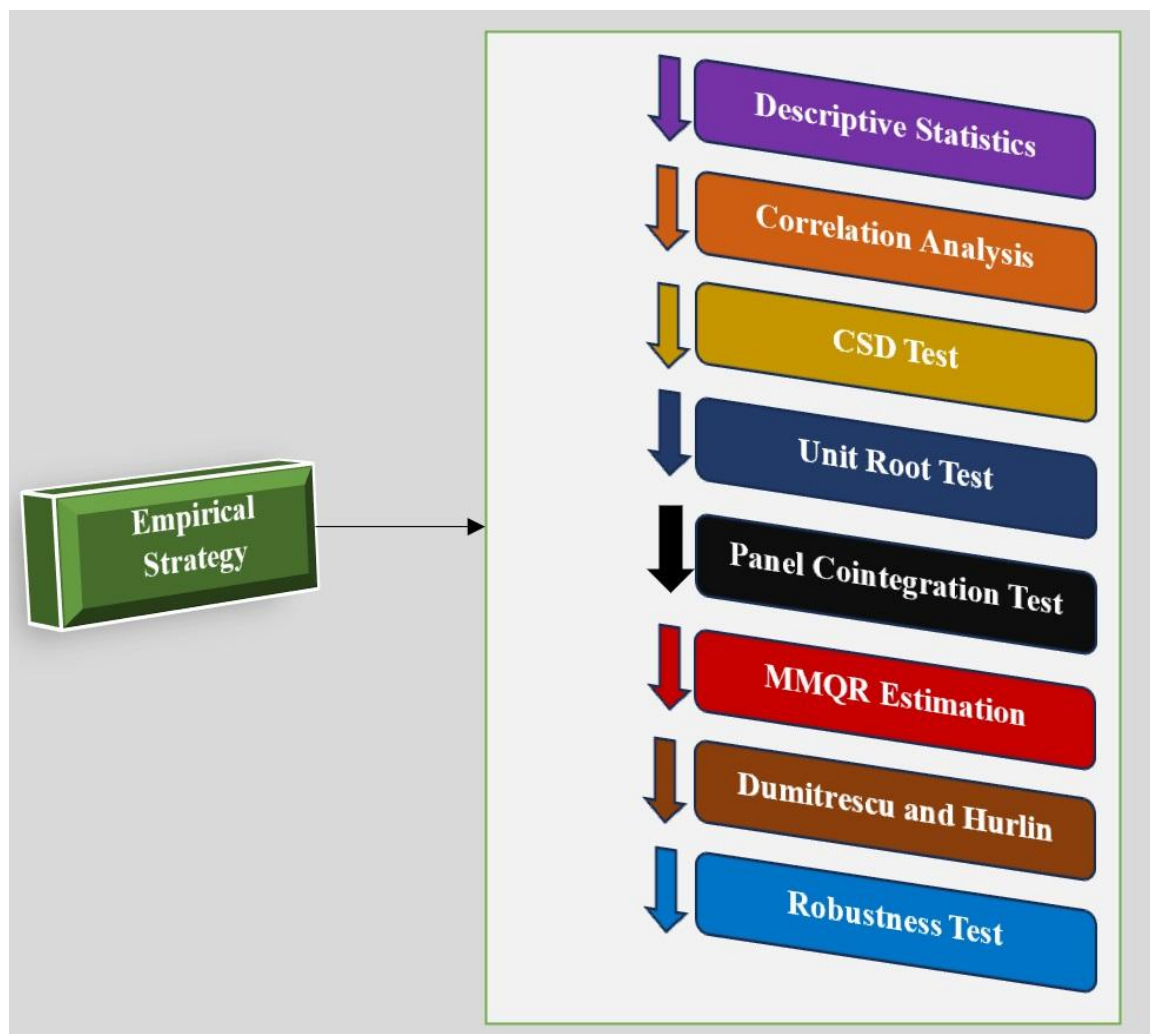


Fig. 2 – Flow chart of empirical strategy. Source: own research

3.3.1 CROSS-SECTIONAL DEPENDENCY (CSD) TEST

In panel data, cross-sectional dependence is a critical concern that must be verified before further investigation. Due to increased interaction across the socioeconomic networks and unobserved common shock, the standard panel estimators are unreliable. Therefore disregarding cross-sectional dependence potentially leads to biased assessments (Sarafidis & Wansbeek, 2012). Since standard unit root tests typically presume cross-sectional independence, cross-sectional dependence must be addressed before further analysis. Nonetheless, depending on techniques that presume cross-sectional independence may lead to unreliable findings. This research implemented the Pesaran CD test (Pesaran, 2004). The test equation is given below:

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{k=i+1}^N \hat{\rho}_{ik} \right) \sim N(0,1) \quad (3)$$

$$i, k = 1, 2, \dots, N (i \neq k)$$

N and T, respectively, indicate the panel size (cross-section) and sample size (period). The CSD test's null hypothesis asserts that cross-sections don't interact and are independent entities.

3.3.2 PANEL UNIT ROOT TEST

The standard unit root test may yield erroneous conclusions because it relies on the assumption of cross-sectional independence in the model. In dealing with the CSD problem, this research employed a second-generation cross-sectional augmented Im, Pesaran, and Shin unit root test developed by Pesaran (2007).

The CIPS test utilizes the following equation.

$$\Delta V_{i,t} = \omega_i + \omega_i X_{i,t-1} + \omega_i V_{t-1} + \sum_{l=0}^P \omega_{il} \Delta \bar{V}_{t-1} + \sum_{l=0}^P \omega_{il} \Delta V_{t-1} \quad (4)$$

Here, the term denotes the cross-sectional average. The above equation provides the cross-sectional augmented Dickey-Fuller (CADF) test. Additionally, the CIPS statistic can be computed using the CADF test.

$$CIPS = \frac{1}{N} \sum_{i=1}^N CADF_i \quad (5)$$

3.3.3 PANEL COINTEGRATION TEST

The current investigation employed the following tests (Kao, 1999; Pedroni, 1999; Westerlund, 2007) to assess the long-term association between the variables under consideration. The Westerlund cointegration test is increasingly popular because it helps address models that contain slope heterogeneity. Furthermore, the cross-sectional dependence can also be addressed by this test. This test estimates the averages of each cross-sectional variable to identify common factors associated with CSD. This test offers greater power because it is adaptable to multiple cross-sections and time-period arrangements. The following is the formulation of the Westerlund cointegration test equation.

$$\Delta X_{i,t} = \omega_i \delta_i + \beta_i (X_{i,t-1} - \theta_i Y_{i,t-1}) + \sum_{j=1}^q \beta_{i,j} \Delta X_{i,t-j} + \sum_{j=0}^q \varphi_{i,j} \Delta Y_{i,t-j} + \varepsilon_{i,t} \quad (6)$$

In equation (6), β_i denotes the error correction parameter, whereas ω_i denotes the vector parameter that connects the cointegration between x and y.

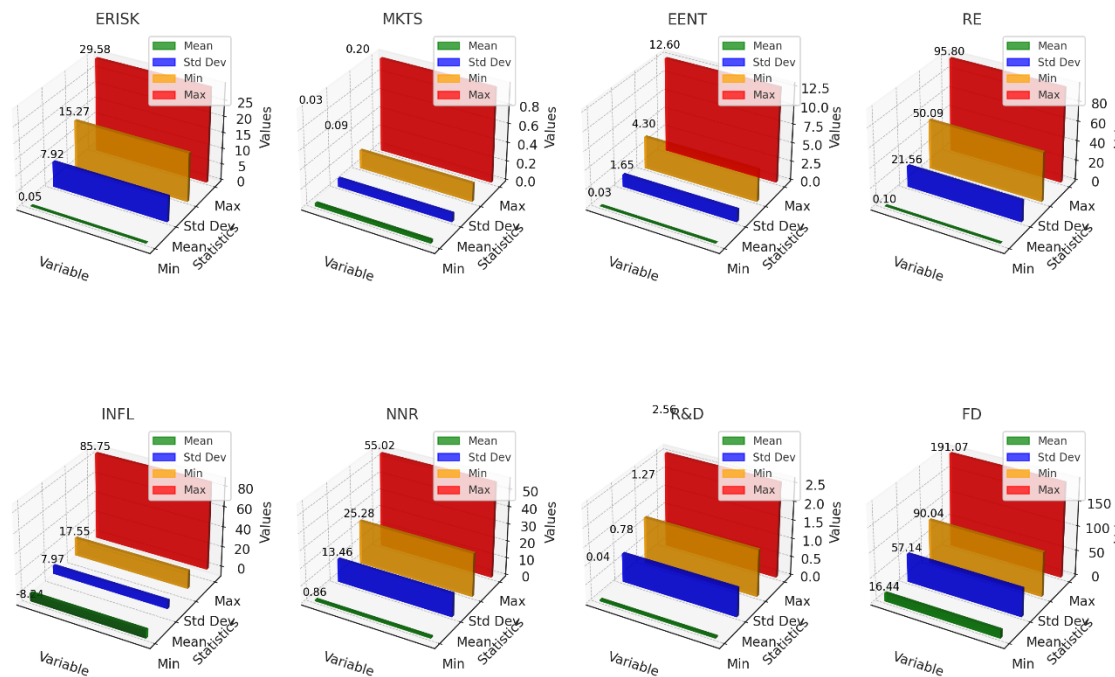


Fig. 3 – 3D surface plots of descriptive statistics. Source: own research

3.3.4 PANEL CAUSALITY TEST

This study employs a panel causality test (Dumitrescu & Hurlin, 2012) to examine the causal relationship among environmental risk, export market structure, environmental entrepreneurship, inflation, natural resource rent, research and development, and financial development. Since the data were non-stationary, this research considered first differences for all variables. This test extends the standard Granger causality equation by incorporating cross-sectional data. This test has higher accuracy because it accommodates diverse time periods and cross-section combinations. The Dumitrescu-Hurlin test applies to both heterogeneous and balanced panel datasets. The findings obtained from this test are dependable in the presence of CSD. The equation is written below.

$$y_{it} = \varphi_i + \sum_{k=1}^p z_i^k y_{i,t-k} + \sum_{k=1}^p x_i^j T_{i,t-k} + \omega_{i,t} \quad (7)$$

In equation (7), z_i^k denotes autoregressive regressors, whereas k indicates lag length.

3.3.5 ROBUSTNESS INVESTIGATION

This study adopted Fully Modified Ordinary Least Squares (FMOLS) and Driscoll and Kraay (1998) standard errors (DKse) with fixed effects for robustness verification, in line with (Jahanger et al., 2024). The FMOLS framework developed by Phillips and Hansen (1990) addresses the influence of cointegration on serial correlation and endogeneity in the explanatory variables. The FMOLS can additionally accommodate stationary errors, integration processes, and polynomial regression of deterministic components. The FMOLS estimation method can also offer estimates of causal relationships among the examined variables (Pedroni, 2001a, 2001b). The DKse exhibits heteroskedasticity, is compatible with autocorrelation, and is robust against common cross-sectional and temporal dependencies (Hoechle, 2007). Models with

fixed effects are used to provide estimates by accounting for continuous variations across countries, hence reducing the impact of heterogeneity bias (Driscoll & Kraay, 1998; Hoechle, 2007).

3.3.6 PANEL ESTIMATION TECHNIQUES

Research employing panel data frequently found the existence of heterogeneity. Thus, identifying this heterogeneity becomes vital. This is because each time a panel data encounters this heterogeneity, it generates ambiguity about the anticipated result, whether they are produced due to their genuine links or exaggerated due to such heterogeneity. Nonetheless, not all panel estimate techniques can detect this heterogeneity; thus, a more specialized approach is required. Due to the possibility of heterogeneity, the present study applied a quantile-based method that can deal with this kind of heterogeneity. The heterogeneity is controlled using quantile-based techniques as the links are examined by constructing the quantile linkage. The panel study by Koenker and Bassett Jr (1978) gives the first evidence of employing the quantile-based technique. Although quantile-based estimates are based on the standard Ordinary Least Square (OLS) estimation framework, they offer more precise findings owing to establishing a relationship with the quantiles. The quantile-based techniques are similarly prone to being shielded against outliers. Furthermore, the obtained result surpasses all the standard methods since the quantile-based estimate techniques do not depend on the average to generate their findings (Binder & Coad, 2011). Nonetheless, the current research employed the most recent one from the quantile fraternity, known as the “Method of Moments Quantile Regression” (MMQR), presented by (Machado & Silva, 2019). Apart from addressing heterogeneity and outliers, this technique is impervious to substantial strikes caused by fixed effects on the outcome. The MMQR estimation approach is particularly suited for this investigation for the following reasons: 1) The MMQR estimation approach is appropriate to account for the distributional and heterogeneous mutations between environmental risk and its specified variables across heterogeneous quantiles within BRICS+ countries. 2) the MMQR offers robust, efficient, unbiased, and reliable estimates under non-linear scenarios compared to any other approach.

The following equation expresses the location-scale variant conditional quantiles;

$$\begin{aligned}
 QERISK_{it} \left(\frac{\tau}{X_{it}} \right) &= \omega_{it} + \omega_1 \ln MKTS_{i,t} + \omega_2 \ln EE_{i,t} + \omega_3 \ln INFL_{i,t} + \omega_4 \ln NNR_{i,t} \\
 &+ \omega_5 \ln R\&D_{i,t} + \omega_5 \ln FD_{i,t} + \varepsilon_{i,t}
 \end{aligned} \tag{8}$$

In equation (8), the τ^{th} quantile function condition is expressed by $QERISK_{it} \left(\frac{\tau}{X_{it}} \right)$, X_{it} displays the independent regressors as explained in equation (2). The scale and location function are further written below:

$$Q_y ERISK_{it} \left(\frac{\tau}{X_{it}} \right) = (\phi_i + \theta_i q(\tau)) + X'_{it} \beta + Z'_{it} \gamma q(\tau) \tag{9}$$

Where the scalar parameter indicating quantile fixed-effect is denoted by $\phi_i + \theta_i q(\tau)$, the $Z_i = Z_i(X)$ demonstrate the k-vector of known differentiable components of X with I element. The independent variables in this technique do not reflect intercept shifts compared to least squares fixed-effects. They are time-independent factors whose heterogeneous impacts are allowed to vary across the quantile of the dependent variable's conditional distribution.

$$\min_q \sum_i \times \sum_t \rho_\tau(A_{it} - (\delta_i + Z_{it}\gamma)q) \quad (10)$$

At this point, $\rho_\tau(A) = (\tau - 1)AI\{A \leq 0\} + TAI\{A > 0\}$ presents the check function.

4 RESULTS AND DISCUSSION

4.1 DESCRIPTIVE STATISTICS AND CORRELATION ANALYSIS

Table 2 presents the descriptive statistics of the investigation. First, the descriptive statistics provide the mean, standard deviation, maximum, and minimum values for environmental risk, export market structure, environmental entrepreneurship, inflation, natural resource rent, and financial development. The Jarque-Bera estimates in Table 2 further validate this study's application of the MMQR estimation approach.

Tab. 2 – Descriptive statistics. Source: own research

Variable	Obs	Mean	Std. Dev.	Min	Max	J-B Stats	Prob.
ERISK	250	7.921	7.346	0.054	29.577	54.85	0.000
MKTS	250	0.089	0.106	0.032	0.996	357.3	0.000
EENT	250	1.647	2.657	0.032	12.597	47.04	0.000
RE	250	21.558	28.53	0.100	95.800	21.27	0.000
INFL	250	7.975	9.576	-8.238	85.746	391.7	0.000
NNR	250	13.463	11.818	0.864	55.024	12.89	0.016
R&D	250	0.778	0.493	0.042	2.561	64.37	0.000
FD	250	57.143	32.894	16.439	191.069	28.65	0.000

Table 3 then displays the estimates from the correlation analysis. The correlations among the variables indicate acceptable levels, and there is no evidence of outliers that could cause multicollinearity issues. Thus, the studied variables appear well behaved before moving to additional essential pre-estimation tests. Figure 3 further illustrates the distributional patterns of the descriptive statistics for the study variables.

Tab. 3 – Correlations Matrix. Source: own research

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) ERISK	1.000							
(2) MKTS	0.088	1.000						
(3) EENT	-0.412	-0.054	1.000					
(4) RE	-0.624	-0.048	0.435	1.000				
(5) INFL	-0.211	0.015	-0.049	0.081	1.000			
(6) NNR	0.477	0.042	-0.451	-0.255	0.090	1.000		

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(7) R&D	-0.030	-0.107	0.378	-0.074	-0.117	-0.454	1.000	
(8) FD	0.759	0.073	-0.359	-0.330	-0.189	0.460	-0.154	1.000

4.2 DIAGNOSTICS TESTS

Table 4 presents the results of the Pesaran test assessing the presence of cross-sectional dependence (CSD) for each variable. This research employed a CSD test to verify the absence of correlation across panel cross-sections. According to the theory, the resulting regression estimates would be biased if there was a correlation, since it is highly likely that a shock in one country would spread to another within the same cross-section. As a result, the present study applied the Pesaran CSD test and revealed significant cross-sectional dependence in the panel. Nonetheless, it further necessitates the implementation of second-generation CADF and CIPS tests for unit root and the Westerlund test for panel cointegration.

The results of the CIPS and CADF unit root tests are reported in Table 5. The CIPS test precisely revealed that, at the level, only natural resources rent, research and development, and inflation are statistically significant for the constant & trend. At the same time, all the other variables are statistically insignificant. However, in first differences, all variables are identified as stationary at the 1% significance level for trend and constant & trend. Thus, these results indicate no unit root problem within the panel dataset. In Table 5, the CADF test results reinforce the outcomes of the CIPS test. Subsequently, the current study applied the Pedroni, Kao, and Westerlund panel cointegration tests to investigate the long-term linkages among environmental risk, export market structure, environmental entrepreneurship, inflation, natural resource rents, research & development, and financial development.

Tab. 4 – Cross-sectional dependence. Source: own research

Variables	CSD-Stats	Prob.
ERISK	11.920	0.000***
MKTS	7.954	0.000***
LnEENT	16.643	0.000***
LnRE	96.770	0.000***
LnINFL	3.117	0.002***
LnNNR	19.164	0.000***
LnR&D	2.045	0.041**
LnFD	4.932	0.000***
Note: *, ** & *** is for the significance level of 10%, 5% and 1%		

Tab. 5 – Unit root test. Source: own research

Variables				
	Level		First Difference	
	C	C&T	C	C&T
CIPS Panel Unit Root Test				
ERISK	-1.509	-1.520	-3.477***	-3.848***

Variables				
	Level		First Difference	
	C	C&T	C	C&T
MKTS	-1.638	-2.440	-4.814***	-4.808***
LnEENT	-1.111	-1.883	-3.572***	-3.883***
LnRE	-0.455	-2.213	-3.402***	-3.565***
LnINFL	-2.940***	-3.051**	-5.292***	-5.103***
LnNNR	-2.515**	-3.698***	-4.940***	-4.914***
LnR&D	-2.894***	-3.085**	-5.131***	-5.266***
LnFD	-1.083	-2.673	-4.223***	-4.000***
CADF Panel Unit Root Test				
ERISK	-1.183	-1.408	-3.477***	-3.684***
MKTS	-1.427	-2.482	-2.730***	-4.808***
LnEENT	-0.665	-1.546	-3.572***	-3.314***
LnRE	-0.352	-2.030	-3.306***	-3.440***
LnINFL	-2.212*	-2.866**	-3.056***	-3.565***
LnNNR	-1.317	-2.480	-2.796***	-4.314***
LnR&D	-2.359**	-2.816**	-3.066***	-3.369***
LnFD	-1.158	-2.620	-4.371***	-3.270***
Note: *, ** & *** is for the significance level of 10%, 5% and 1%				

Table 6 illustrates the findings of Pedroni and Kao's cointegration tests for the panel dataset. The findings presented demonstrate that the dependent variable and all explanatory variables are significantly cointegrated. The Westerlund cointegration test further validates the reported outcomes, as presented in Table 6. Thus, the reported cointegration test results confirm the presence of cointegration among all variables in the panel dataset. After meeting all essential criteria, the present research used the MMQR estimation approach for analysis and hypothesis testing.

Tab. 6 – Panel cointegration test. Source: own research

	Pedroni (1999)			Kao (1999)	Decision
	MPP t	PP t	ADF t	ADF t	Cointegration exist
Statistics	2.427***	-4.551***	-4.988***	-2.481***	
p-value	0.008	0.000	0.000	0.007	
Westerlund test (2007)					
Statistics	Gt	Ga	Pt	Pa	
Value	-1.580**	-1.912	-6.184***	-1.903	
Z-value	-1.836	1.314	-3.915	-0.957	
p-value	0.033	0.906	0.000	0.169	
Note: *, ** & *** is for the significance level of 10%, 5% and 1%					

4.3 BENCHMARK REGRESSION MMQR

The MMQR findings are presented in Table 7 for Models 1, 2, and 3. Model 1 explores the relationship between export market structure and environmental risk in BRICS+ countries.

Tab. 7 – MMQR estimates. Source: own research

Variables	Location	Scale	Quantiles								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
DV: Environmental risk (CO2 Emissions)											
Model 1											
MKTS	0.173**	0.040	0.102	0.134	0.151*	0.164**	0.177**	0.188***	0.202**	0.220***	0.244**
LnINFL	-0.344***	-0.112*	-0.142	-0.232*	-0.282**	-0.317***	-0.354***	-0.385***	-0.426***	-0.475***	-0.544***
LnNNR	0.205***	-0.037	0.272***	0.242***	0.226***	0.213***	0.201***	0.191***	0.178***	0.161**	0.139*
LnR&D	0.299***	-0.153***	0.505***	0.382***	0.315***	0.266***	0.215***	0.174**	0.118	0.051	-0.043
LnFD	1.421***	0.120	1.205***	1.301***	1.354***	1.392***	1.432***	1.465***	1.509***	1.561***	1.634***
Model 2											
LnEENT	-0.249***	0.073*	-0.366***	-0.329***	-0.288***	-0.264***	-0.242***	-0.222***	-0.193**	-0.149*	-0.121
LnINFL	-0.332***	-0.142*	-0.106	-0.176	-0.256*	-0.302**	-0.345***	-0.383***	-0.440***	-0.524***	-0.579***
LnNNR	0.115*	-0.028	0.159*	0.145**	0.130*	0.121*	0.113*	0.105	0.094	0.077	0.067
LnR&D	0.218***	-0.211***	0.554***	0.450***	0.330***	0.263***	0.201***	0.143*	0.058	-0.067	-0.149
LnFD	1.347***	0.100	1.187***	1.237***	1.293***	1.326***	1.355***	1.383***	1.423***	1.482***	1.521***
Model 3											
LnRE	-0.319***	-0.032***	-0.269***	-0.285***	-0.296***	-0.307***	-0.315***	-0.330***	-0.342***	-0.356***	-0.374***
LnINFL	-0.144**	0.044	-0.214***	-0.191***	-0.176***	-0.161***	-0.151**	-0.130**	-0.126	-0.094	-0.068
LnNNR	-0.171***	-0.050**	-0.092**	-0.118***	-0.136***	-0.152***	-0.164***	-0.188***	-0.208***	-0.229***	-0.258***
LnR&D	0.157***	-0.071***	0.270***	0.233***	0.208***	0.184***	0.167***	0.133***	0.104**	0.074	0.033
LnFD	0.909***	0.012	0.889***	0.896***	0.900***	0.904***	0.907***	0.913***	0.918***	0.924***	0.931***
Note: *, ** & *** is for the significance level of 10%, 5% and 1%											

The MMQR results in Model 1 show that export market structure has a positive effect on environmental risk in BRICS+ countries. Because MKTS is measured by the Herfindahl-Hirschman Index (HHI), where higher values indicate greater export market concentration and lower values indicate a more competitive export market structure, the positive coefficient implies that greater export market concentration increases environmental risk.

Conversely, a more competitive export market structure is associated with lower environmental risk. The coefficients at the 10th and 20th quantiles are positive but statistically insignificant, whereas the coefficients from the 30th to the 90th quantiles are positive and statistically significant. Moreover, the magnitude of the coefficient increases across higher quantiles, indicating that the adverse effect of export market concentration is stronger in countries located at higher levels of environmental risk. Environmental risk is one of the primary ecological challenges caused by the buildup of CO2 emissions in the atmosphere. The results support the market power hypothesis in this context by suggesting that more competitive export markets may encourage efficiency, innovation, and cleaner production practices that help reduce environmental risk. These results are consistent with Chen et al. (2024), who found that greater competition decreases CO2 emissions, but they differ from Zhu et al. (2024), who reported that greater competition increases CO2 emissions. Therefore, this research accepts H1, which posits

that export market structure significantly affects environmental risk in BRICS+ countries. Furthermore, natural resource rent, research and development, and financial development positively and significantly affect environmental risk, whereas inflation has a negative and significant effect on environmental risk.

Subsequently, this study examines the impact of environmental entrepreneurship on environmental risk in BRICS+ countries. This research used two comprehensive measurement proxies of environmental entrepreneurship: 1) % of electricity production from renewables relative to overall electricity production, and 2) % of renewable energy consumption relative to total energy consumption. In model 2, the empirical evidence revealed that environmental entrepreneurship (% of electricity production from renewables relative to overall electricity production) negatively and significantly influences environmental risk. The coefficient value of the 90th quantile is -0.121, indicating a negative but statistically insignificant impact. However, the coefficient values from the 10th to 80th quantiles show a negative and statistically significant relationship between environmental entrepreneurship and environmental risk, which categorically implies that a 1% increase in renewable electricity production as a percentage of total electricity production results in a reduction of environmental risk by -0.366, -0.329, -0.288, -0.264, -0.242, -0.222, -0.193, and -0.149 from 10th to 80th quantiles respectively. Notably, the coefficient exhibited a diminishing pattern across lower to higher quantiles, suggesting that renewable electricity can strongly mitigate risk in countries with moderate to low environmental risk. Nonetheless, the control variables, natural resources rent, financial development, and research and development, contribute to the environmental risk, while inflation helps mitigate environmental risk in BRICS+ economies.

In model 3, this study incorporated the second proxy to examine the impact of environmental entrepreneurship (% increase in renewable energy consumption as a percentage of total energy consumption) on environmental risk in BRICS+ countries. The empirical evidence reveals that a 1% increase in renewable energy consumption as a share of total energy consumption reduces environmental risk by -0.269, -0.285, -0.296, -0.307, -0.315, -0.330, -0.342, -0.356, and -0.374 across the 10th to 90th quantiles, respectively. As the quantile level ascends, the associated coefficient values increase accordingly. This increasing trend precisely reflects that countries facing higher environmental risk can leverage renewable energy consumption to achieve rapid decarbonization. Nevertheless, control variables inflation and natural resources revenue negatively correlate with environmental risk, while research & development and financial development are positively associated with environmental risk.

Collectively, this empirical evidence from models 2 and 3 demonstrates that increasing environmental entrepreneurship initiatives through renewable energy sources substantially mitigates environmental risk in BRICS+ countries. This also underscores the contribution of BRICS+ to environmental entrepreneurship in accomplishing the SDGs' goals of mitigating climate change risk. These empirical results are consistent with prior investigations (Sun, Pofoura, et al., 2020), which claimed that environmental entrepreneurship helps to promote sustainable development. These outcomes are also in tandem with (S. Khan et al., 2022; Riti et al., 2022), who found renewable electricity production and renewable energy consumption to be strong candidates for the fight against climate change risk. Thus, this study accepts H2,

which posits that environmental entrepreneurship significantly mitigates environmental risk in BRICS+ countries. Figure 4 presents 3D surface plots of MMQR estimates.

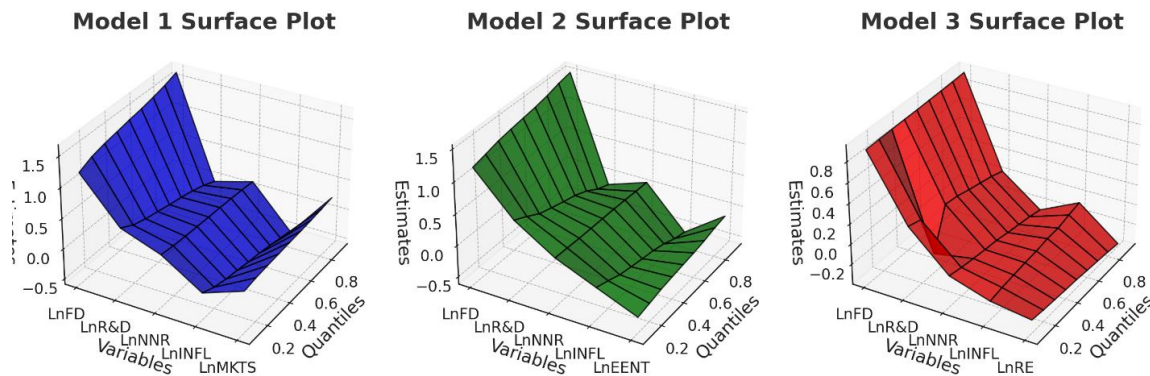


Fig. 4 – 3D surface plots of MMQR estimates. Source: own research

4.4 DUMITRESCU-HURLIN CAUSALITY TEST

Furthermore, Table 8 displays the outcomes of the Dumitrescu and Hurlin (2012) panel causality test. According to the reported outcomes, bidirectional causality exists between environmental risk and MKTS, LnEENT, LnINFL, LnNNR, LnR&D, and LnFD in BRICS+ countries. These findings align with the main results by indicating that a more competitive export market structure (that is, lower concentration) and environmental entrepreneurship are relevant for mitigating environmental risk in the BRICS+ countries.

Tab. 8 – Dumitrescu-Hurlin test. Source: own research

Null Hypothesis	W-stat.	Z-bar	P-value	Decision
MKTS → ERISK	4.280	3.606	0.000	Bidirectional causality exists between environmental risk and the variables reported in Table 8.
ERISK→ MKTS	3.719	6.079	0.000	
LnEENT → ERISK	4.922	4.620	0.000	
ERISK→ LnEENT	6.554	7.201	0.000	
LnINFL → ERISK	2.664	3.720	0.000	
ERISK→ LnINFL	2.966	4.397	0.000	
LnNNR → ERISK	15.859	9.000	0.000	
ERISK→ LnNNR	2.487	3.325	0.001	
LnR&D → ERISK	3.354	5.264	0.000	
ERISK→ LnR&D	4.192	7.138	0.000	
LnFD → ERISK	2.489	3.327	0.001	
ERISK→ LnFD	4.989	8.919	0.000	
Bidirectional causality exists between environmental risk and the variables reported in Table 8.				

4.5 ROBUSTNESS CHECK

Table 9 displays the results of the robustness tests. This study employed FMOLS and DKse estimation methodologies for robustness verification following Jahanger et al. (2024). Although coefficient magnitudes vary across variables, the overall pattern remains consistent with the MMQR estimates. The coefficients derived from the FMOLS and DKse methodologies reinforce the main findings. Across both methodologies, export market structure is positively

and significantly associated with environmental risk, indicating that greater export market concentration increases environmental risk in BRICS+ countries. Environmental entrepreneurship is significantly and negatively associated with environmental risk, highlighting the importance of renewable electricity production and renewable energy consumption in mitigating environmental risk. These estimation methodologies support the robustness of the results; however, the central objective of this research is to provide estimates that reflect heterogeneous influences across the conditional distribution rather than relying solely on average effects. The MMQR results show that the effects of the regressors vary across quantiles, with several coefficients being statistically significant at different points of the conditional distribution.

Tab. 9 – Robustness check. Source: own research

Variables DV: Environmental risk	FMOLS			Dkse		
	Coeff.	t-stats	Prob.	Coeff.	t-stats	Prob.
<i>Model 1</i>						
MKTS	0.401	1.99	0.047	0.170	2.64	0.015
LnINFL	-1.043	-5.03	0.000	-0.382	-1.78	0.089
LnNNR	0.513	3.22	0.001	0.239	2.04	0.053
LnR&D	0.368	2.35	0.019	0.251	3.30	0.003
LnFD	0.741	3.95	0.000	1.412	5.48	0.000
<i>Model 2</i>						
LnEENT	-0.363	-1.86	0.063	-0.249	-4.91	0.000
LnINFL	-1.064	-5.17	0.000	-0.332	-1.92	0.067
LnNNR	0.393	2.14	0.032	0.115	1.61	0.121
LnR&D	0.340	2.22	0.026	0.218	4.46	0.000
LnFD	0.603	3.79	0.000	1.347	9.65	0.000
<i>Model 3</i>						
LnRE	-0.318	-6.64	0.000	-0.319	-20.68	0.000
LnINFL	-0.202	-1.11	0.266	-0.144	-1.99	0.058
LnNNR	-0.136	-1.09	0.278	-0.171	-2.42	0.023
LnR&D	0.188	1.95	0.051	0.157	4.19	0.000
LnFD	0.899	3.96	0.000	0.909	9.78	0.000

4.6 ADDITIONAL ROBUSTNESS CHECK

Following the baseline MMQR regression and robustness checks using FMOLS and DKse, we conducted additional robustness checks in two ways. First, we used linear interpolation as an alternative method for supplementing missing data (Danisman & Tarazi, 2020; Yu, Long, & Shahzad, 2026). Second, we incorporated additional control variables into the baseline model to capture the true impact of the main independent variables on the dependent variable. Specifically, we included trade openness to capture the environmental implications of international trade, GDP per capita to capture how economic prosperity affects environmental risk, and population density to account for the potential environmental implications of demographic pressure. The results of these additional robustness checks are presented in Table

10. Overall, the additional checks broadly support the baseline conclusion that greater export market concentration is associated with higher environmental risk, especially at the middle and upper quantiles, while both proxies of environmental entrepreneurship continue to reduce environmental risk. At the same time, the coefficients display substantial heterogeneity across quantiles.

Tab. 10 – Additional robustness check. Source: own research

Variables	Location	Scale	Quantiles								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Model 1											
MKTS	0.088	0.086**	-0.041	-0.011	0.030	0.067	0.097	0.129**	0.158**	0.183***	0.213***
LnINFL	-0.046	-0.090*	0.088	0.057	0.015	-0.024	-0.056	-0.089	-0.119	-0.144*	-0.176*
LnNNR	0.007	-0.018***	0.034**	0.027**	0.019	0.012	0.005	-0.001	-0.007	-0.012	-0.019
LnR&D	0.010	0.024**	-0.025	-0.017	-0.006	0.004	0.013	0.022	0.030	0.037*	0.045*
LnFD	0.726***	0.161**	0.487***	0.543***	0.619***	0.687***	0.743***	0.804***	0.857***	0.903***	0.953***
LnTO	-4.314***	-1.120**	-2.530**	-2.946**	-3.512***	-4.022***	-4.441***	-4.890***	-5.290***	-5.628***	-6.051***
LnGDP	0.003***	-0.008***	0.005***	0.004***	0.004***	0.003***	0.003***	0.003***	0.002***	0.002***	0.002***
LnPD	-0.039***	-0.003*	-0.034***	-0.035***	-0.037***	-0.038***	-0.039***	-0.041***	-0.042***	-0.043***	-0.044***
Model 2											
LnEENT	-0.336***	0.021	-0.367***	-0.358***	-0.348***	-0.342***	-0.335***	-0.328***	-0.322***	-0.316***	-0.301***
LnINFL	-0.010	-0.103	0.146	0.097	0.052	0.021	-0.013	-0.046	-0.073*	-0.107**	-0.177**
LnNNR	-0.005	-0.013*	0.015	0.009	0.003	-0.001	-0.005	-0.010	-0.013**	-0.017*	-0.026**
LnR&D	0.023	0.026*	-0.017	-0.004	0.007	0.015	0.024	0.033	0.040	0.049*	0.066*
LnFD	0.848***	0.114	0.675***	0.729***	0.779***	0.814***	0.852***	0.892***	0.919***	0.958***	1.035***
LnTO	-5.510***	-0.747	-4.378***	-4.732***	-5.056***	-5.285***	-5.534***	-5.793***	-5.971***	-6.224***	-6.730***
LnGDP	0.004***	-0.009***	0.006***	0.005***	0.005***	0.004***	0.004***	0.003***	0.003***	0.002***	-0.002***
LnPD	-0.032***	0.001	-0.033***	-0.033***	-0.032***	-0.032***	-0.031***	-0.031***	-0.030***	-0.030***	-0.029***
Model 3											
LnRE	-0.242***	-0.445***	-0.185***	-0.198***	-0.206***	-0.220***	-0.240***	-0.260***	-0.273***	-0.291***	-0.327***
LnINFL	-0.041	0.015	-0.060	-0.055	-0.053	-0.048	-0.042	-0.035	-0.031	-0.025	-0.013
LnNNR	-0.058***	-0.029***	-0.021*	-0.055	-0.035***	-0.044***	-0.056***	-0.069***	-0.078***	-0.089***	-0.113***
LnR&D	-0.006	0.024*	-0.037*	-0.030**	-0.025*	-0.018	-0.008	0.003	0.010	0.020	0.039
LnFD	0.488***	0.058	0.414***	0.431***	0.441***	0.459***	0.484***	0.510***	0.527***	0.551***	0.597***
LnTO	-2.806***	-0.413	-2.281***	-2.401***	-2.472***	-2.601***	-2.781***	-2.964***	-3.087***	-3.256***	-3.587**
LnGDP	0.001***	-0.001***	0.002***	0.002***	0.002***	0.001***	0.001***	0.001**	0.001	0.000	-0.002
LnPD	-0.027***	-0.001	-0.026***	-0.027***	-0.027***	-0.028***	-0.028***	-0.028***	-0.029***	-0.029***	-0.030***
Note: *, ** & *** is for the significance level of 10%, 5% and 1%											

5 CONCLUSION

The evaluation and management of ecological sustainability have emerged as essential challenges in the global fight against climate change and its consequences. Policymakers are keen to identify ways to reduce CO2 emissions and mitigate environmental risks. In line with SDG 13, this research examines the influence of export market structure and environmental entrepreneurship on environmental risk in BRICS+ countries using panel data from 1998 to 2022. The analysis first applies the Pesaran CSD test, followed by the CIPS and CADF tests for stationarity and the Pedroni, Kao, and Westerlund tests for panel cointegration. After satisfying these pre-estimation requirements, the study employs the MMQR technique to obtain

distribution-sensitive estimates. The MMQR results show that export market structure has a significant positive effect on environmental risk. Since export market structure is measured using the HHI, this finding indicates that greater export market concentration increases environmental risk, whereas a more competitive export market structure helps reduce it. The effect is stronger at higher quantiles of environmental risk, suggesting that countries facing greater environmental pressure are more vulnerable to concentrated export structures. The results also show that environmental entrepreneurship has a significant negative effect on environmental risk. Using renewable electricity production and renewable energy consumption as proxies, the analysis confirms that environmental entrepreneurship can serve as an effective mechanism for mitigating climate-related environmental risk in BRICS+ countries. In addition, the Dumitrescu-Hurlin, FMOLS, and DKse results support the main findings, although the causality evidence applies only to the variables included in the causality model.

5.1 POLICY IMPLICATIONS

The outcomes of this research fall under SDG 13 and suggest that a more competitive export market structure can help mitigate environmental risk. The study also identifies environmental entrepreneurship as a sustainable energy-based pathway for combating climate change. Based on the empirical evidence and in line with UN SDG 13, which emphasizes climate action, BRICS+ countries should take immediate steps to combat climate change and mitigate environmental risks by embracing the following policy recommendations.

Policy 1: Ecological sustainability is central to climate action in BRICS+ countries. The MMQR results show that the effect of export market concentration on environmental risk is not statistically significant at the lower quantiles, but it becomes positive and significant from the middle to the upper quantiles. This indicates that countries facing moderate to high environmental risk are more adversely affected by concentrated export market structures. Accordingly, policymakers should encourage export diversification, green export upgrading, cleaner production systems, and market incentives that support low-carbon production. Such measures can help countries move toward a more competitive and environmentally sustainable export structure, thereby reducing environmental risk.

Policy 2: The outcomes indicate that environmental entrepreneurship (renewable electricity production as a % of total electricity production) has a robust negative impact on environmental risk, with a declining trend from lower to higher quantiles. Precisely, these outcomes suggest that lower- and middle-risk environmental countries can leverage renewable electricity production to achieve rapid decarbonization. The think tanks standing at the lower to middle quantiles of environmental risk should therefore enforce stringent environmental policies, particularly those related to renewable electricity generation. Moreover, governing institutions should ensure an inclusive green environment, coupled with financial incentives and cleaner production technologies, to put BRICS+ countries on the path to environmental prosperity.

Policy 3: The outcomes revealed that environmental entrepreneurship (renewable energy consumption as a % of total energy consumption) is crucial for promoting ecological sustainability by mitigating environmental risks in BRICS+ countries. Interestingly, the outcomes show a clear heterogeneity and an increasing trend from lower to higher quantiles of

environmental risk. This suggests that renewable energy consumption is a more viable solution for countries with higher emissions to mitigate environmental risk. Nonetheless, the government and policymakers should create incentives and promote environmental entrepreneurial initiatives. This will stimulate renewable energy production and consumption, thereby reducing climate change risks associated with the UN's SDGs. BRICS+ countries should prioritize the production and use of renewable energy in their national energy strategies. This will also help reduce environmental risk by reducing reliance on fossil fuels.

Policy 4: The BRICS+ countries should develop financial mechanisms to encourage the expansion of sustainable, cleaner production for export products and markets. In parallel, BRICS+ economies should encourage the initiative dedicated to environmental entrepreneurial activities, particularly those that embrace renewable energy as a viable means of mitigating environmental risk. The authorities of these countries can set quotas for renewable energy generation and consumption in industries to accelerate these transitions.

5.2 RESEARCH LIMITATIONS

This study identifies limitations that might be addressed in further examinations. The first limitation is the inconsistency in the data for the chosen countries and the time-bound scope. Future studies, however, could incorporate global perspectives with similar aims. The current research used CO₂ emissions to signify environmental risk; further studies could use the load capacity factor as an indicator, contingent upon data availability. Notably, environmental risk mitigation is the primary focus of this research within the United Nations SDGs. However, future studies can broaden the scope of the research by investigating the impact of export market structure on economic, social, and governance indicators or aggregate ESG indicators of sustainable development. Finally, future research could include a comparative examination of developed and developing countries to support generalization.

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