Do the shocks in technological and financial innovation influence the environmental quality? Evidence from BRICS economies

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Do the shocks in technological and financial innovation influence the environmental quality? Evidence from BRICS economies

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Abstract: The current paper formulates a novel framework to scrutinize the effects of shocks in technological and financial innovation on carbon dioxide emissions (CO2e) in BRICS economies. The Westerlund cointegration test is applied to confirm the long-run association among the constructs. The estimates of second-generation techniques, viz, Augmented Mean Group (AMG) and Common Correlated Effect Mean Group (CCEMG), determine the following results. First, the positive shocks from financial innovation significantly disrupt the CO2e, while financial innovation's adverse shocks cause to stimulate pollution. Second, positive shocks in technological innovation also plays a pivotal role in mitigating carbon emissions while the negative shocks exhibit no impact. Third, the process of urbanization exhibits a negative linkage with environmental degradation. Fourth, fossil fuel consumption demonstrates a positive association with CO2e. Lastly, the negative correlation between foreign direct investment-CO2e nexus and GDP per capita squared-CO2e nexus assert the existence of EKC hypothesis, respectively. Also, fully-modified OLS is also deployed for country-level analysis. Besides, the causality test validates the findings by confirming the causal relationship among the modelled variables. Based of the study outcomes, this study has recommended an SDG-oriented policy framework.

Keywords: Financial innovation, Technological innovation, CO2e, FDI, urbanization, BRICS.

JEL classification: O31, O33, Q53, Q54

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1. Introduction

Global warming has been a pressing concern for the policymakers around the world. The persisting economic growth trajectory is creating an environmental pressure, and bringing transformation to this trajectory entails shifting the energy sources towards renewable sources. This transformation can be enabled by technological innovations, and thereby, can build the foundation for sustainable development. The recent Sustainable Development Goals (SDG) progress report 2020 stresses on this aspect, while talking about the role of innovations in attaining the SDG objectives. This role might prove to be critical for the emerging economies, as the pro-growth objective of these nations sometimes compel the policymakers to tread along the growth trajectory, even at the cost of environmental quality. In order to restore the ecological balance and ensure sustainable development, the role of technological innovation needs to be recognized in these nations. In this regard, the BRICS economies need a special mention. The IPCC (2018) and ISPBES (2019) reports show the climatic vulnerability of the BRICS countries, and this issue surfaced again during the *12th BRICS Summit* in St. Petersburg. The recommendations provided in the summit revolved around utilizing the capacity to innovate for betterment of the environmental quality. The *5th Meeting of BRICS Ministers of Energy* in 2020 also focused on technological interoperability and facilitating investment in energy.[2] This policy discourse gives an idea the rising concern of the policymakers for the worsening climatic condition in the BRICS nations need policy interventions regarding technological innovation, along with necessary financialization. There lies the focus of the present study.

Now, the discussion on the technological innovations for transforming the economic growth pattern essentially involves the discovery of alternate energy solutions. The dependence of the

[2] https://eng.brics-russia2020.ru/news/20201016/874938/Energy-Ministers-highlight-major-role-of-the-BRICS-countries-in-the-global-energy-system.html

BRICS countries on the fossil fuel-based energy sources is responsible for the eroding of environmental quality, and a straightforward solution is to replace these energy sources with the renewable energy sources. However, even appearing to be simple, this shift might have several policy implications. One of the major reasons behind this is the risk associated with the renewable energy projects. Because of the persisting difference in the resource endowment and technological capabilities, the mutual interests of the nations are sometimes compromised, leading to the rise in the risk of these projects. The *Energy Technology Report 2020* published by BRICS Energy Research Cooperation Platform (2020) refers to these precursors of the risk involved in the renewable energy projects. Although the 2016 report by Institute for Energy Economics and Financial Analysis (IEEFA, 2016) has paved some ways for achieving the financial targets for the renewable energy projects in the BRICS countries, the 2020 energy sector assessment report by the BRICS Youth Energy Agency (2020) has clearly shown that the unprecedented geopolitical events have circumvented the financing of those projects, and so, increasing their risk profiles. In such a situation, going beyond the traditional financing mechanisms might serve the purpose. In the *37th Round Table on Sustainable Development* at the Organization for Economic Co-operation and Development (OECD) has given a recommendation of looking into financial innovation for financing the renewable energy projects (Cervantes et al., 2018). A similar kind of solution was also provided by the *International Partnership for Energy Efficiency Collaboration* in their G20 Energy Efficiency Finance Task Group report (IPEEC, 2016). Given these evidences, it can be assumed that financial innovation might play a pivotal role in the betterment of the environmental quality by sustaining the financing solutions for the renewable energy projects.

However, from the perspective of policymaking, it is also important to maintain the technological and financial innovation trajectory, so that the issue of environmental degradation can be tackled in a sustained manner. This aspect might prove to be critical from the point of view of attaining the objectives of SDG 13 (climate action) and SDG 7 (affordable and clean energy). Owing to the geopolitical shocks to the international relations, the innovation capabilities in these nations might face crests and troughs. During these phases, the impact might be visible on the renewable energy projects, and consequently, on the environmental quality. Moreover, the economic activities might also be impacted by these shocks, resulting in possible fluctuations in the environmental impacts. In order to reduce the climatic variabilities arising out of these shocks, the policy interventions should be able to internalize the negative environmental externalities of these shocks. Recommending these policy interventions for the BRICS countries is the objective of the present study, and the research question of the study can be articulated as the following:

Research Question*: Do the shocks in technological and financial innovation influence the environmental quality in the BRICS economies?*

Given the research objective, the present study aims to develop an SDG-oriented policy framework for internalizing the environmental externalities arising out of the shocks in the technological and financial innovation in the BRICS countries. This policy framework is aimed at addressing the objectives of SDG 13 and 7, by means of the innovation capabilities of the BRICS countries. While the policy framework developed in the study aims at the BRICS countries, this framework has the aspect of generalizability towards the other emerging nations suffering from the climatic issues. Developing the SDG-oriented policy framework by encapsulating the shocks to innovation capabilities for the BRICS countries defines the policy-level contribution of the study.

Developing the policy framework also requires to capture the evolutionary impacts of the policy instruments on the target policy indicator. This particular aspect is covered by choosing the analytical framework of the Environmental Kuznets Curve (EKC) hypothesis (Shahbaz and Sinha, 2019). Choice of this framework complements the research objective. Moreover, the BRICS countries might be associated with each other via socio-economic spillovers, and this might result in estimation issues. This problem has been handled by choosing the second-generation methodological approach. The research objective is complemented by this metholodigical orientation.

The remainder of the study is organized as follows. The literature review is presented in section 2, while section 3 discusses the theoretical background for model specification. In section 4, data sources and econometric techniques for estimation are elaborated. The findings and discussion are presented in section 5, while section 6 consists of the conclusion, policy recommendations, and limitations of the study.

2. Literature Review

2.1. Technological innovation and environmental quality

Technological innovations have been a major driver of economic growth, and hence, they have also been responsible for the environmental externalities caused by the growth trajectory. Driven by the policy orientation of the organizations and the policymakers, this impact can be positive or negative. The study by Messeni Petruzzelli et al. (2011) has discovered the role of inter- and intra-organizational relationships to realize the potential of green innovations. This study gives an indication that the goal convergence might lead to the effectiveness of the technological innovations in shaping the environmental quality. The study by Ardito et al. (2019b) reaffirms this argument. Rising concerns regarding the environmental issues is now compelling the policymakers to promote the technological innovations towards the betterment of environmental quality (Ardito et al., 2016, 2019a). Along with developing and promoting the innovation capabilities, the policymakers are also concerned about diffusing these innovations, so that the potential environmental benefits of these innovations can be achieved at various levels of the economy (Aldieri et al., 2021; Dell'Anna, 2021).

The literature on the environmental impact of technological innovations provides with mixed results. The study by Shaari et al. (2016) shows the environmental benefits of research and development in case of the developed economies. A finding of similar kind can be seen in the study by Álvarez-Herránz et al. (2017) for the OECD countries. The study by Churchill et al. (2019) on the G7 countries and Fernández et al. (2018) for the EU countries also yield similar results. Largely, the cross-country evidences for the developed economies reveal that the technological innovations internalize the negative environmental externalities caused by the economic growth trajectory. The studies conducted on the single developed countries also nearly yield similar results. The study by Shahbaz et al. (2018) for France and Dinda (2018) for the USA show that the technological progression has helped those countries in improving the environmental quality. However, the study by Mensah et al. (2018) on the OECD countries has provided with mixed evidence with respect to the impact of technological innovation on environmental quality.

On the other hand, contradicting findings can be seen in case of the developing or emerging economies. The study by Santra (2017) has shown the negative environmental impacts of innovation for the BRICS countries. On the flipside, the study by Sinha et al. (2020a) for the case of the MENA countries has shown that the technological innovation can reduce emissions to a certain extent, and the innovations might turn out to be ineffective at the higher level of emissions. A consecutive study by Sinha et al. (2020b) for the Asia-Pacific countries show that the prevailing innovations policies in these countries are ineffective in reducing environmental degradation. The policy level ineffectiveness in driving the environmental degradation down through innovations has also been shown by Sinha et al. (2020c) for the Next 11 economies. However, the study by Zafar et al. (2021) for the Asia-Pacific countries show that the technological innovations are capable of reducing the environmental degradation. A similar kind of finding can also be seen in case of the BRICS countries by Chien et al. (2021a).

2.2. Financial innovation and environmental quality

Financial innovation refers to the innovations in the financial products for better management of financial risk, transferring of risk, and efficient management of credit and liquidity. Following the work of Miller (1986), financial innovation includes innovative derivative products, alternate risk allocation products, exchange linked funds, and alternatives of tax-deductible equity. In order to suffice the innovation initiatives within a nation, these products are necessary to fulfill the financial needs (Silber, 1983). Following the invention and diffusion components of innovation, financial innovation is also carried out by product and process innovations, which are subject to the demand of the economic systems of the nations. While the innovation endeavors are directed towards combating the climatic shift, it is expected the financialization of those endeavors will also require certain levels of innovation. This neo-financialization channel is essential due the risk associated with the projects. From this perspective, it might be assumed that financial innovation might have an impact on the environmental degradation, although through an indirect channel.

Since the development of the pollution trading market, the financial innovation has been envisaged as a tool to finance the environment-related projects. The work of Allen (2012) has reflected upon how financial innovation has been able to complement the Clean Water Act in the USA by introducing the state revolving funds, debt-for-nature swaps, and individual transferable fishing quotas. If the dimension of renewable energy generation is analyzed, then the work of Delimatsis (2009) sheds light on the trading of the renewable energy certificates in the secondary market, and how it has a significant impact in promoting renewable energy solutions. By virtue of this innovative financial product, majority of the developed nations are on the way to reduce the consumption of fossil fuel-based energy sources. The reflection of the arguments put forth by Delimatsis (2009) is reflected in the work of Yuan et al. (2021) for the OECD countries. The work revealed that the financial innovation promotes the green innovation, especially in presence of the stricter environmental regulations and lower degree of banking competition. To discuss on the specific instruments, carbon finance has been one of the major innovative financial measures to combat environmental degradation. The work of Tian et al. (2017) shows that the carbon finance is a major constituent of innovative financial macroenvironment in China, and it is responsible for the decline in the carbon intensity. Now, reference to such instruments evidently points the debate towards the Nordic countries, which are considered as the front-runners in climate financing. However, the study by Cheng et al. (2021) shows that the carbon tax might not be effective in promoting energy innovation beyond a certain point, as this instrument might be envisaged by the industrial sector as a tax-saving mechanism, rather than an ecological protection measure. On this note, the evidence presented by Chien et al. (2021b) shows that the financial innovation has been effective in reducing the environmental degradation in the Asian economies, which contradicts the finding of Cheng et al. (2021).

2.3. Research gap

Given the brief discussion on literature on the environmental impacts of technological and financial innovations, it is evident that both the innovation endeavors have mixed impacts on the environmental quality. However, in all of the studies, the impact of both the innovations have been measured in a unilateral manner, i.e., the studies have an inherent assumption that the upward or downward movements in the innovation endeavors might have the environmental impacts of alike magnitude. Given the exogeneities in the economic structure of the nations, this assumption might not be a plausible one, and the present study aims to address this issue. The present study is built on the premise that the shocks of both the innovations might have differential impacts on the environmental quality, and thereby, the study aims to contribute to the literature.

3. Theoretical Framework

Financial innovation plays a pivotal role in stimulating economic activities, and thereby, it can be inferred that it can be a useful tool to curb the CO2e. It can be assumed that market imperfections, shocks in the efficiency of the financial markets, shocks in the risk value, shocks in the household decisions regarding the saving and borrowing, profit motives of the financial sector, variations in the finance-based needs of firms, and macroeconomic factors are accountable for creating positive and negative shocks in financial innovation. Further, it is conjectured that on account of asymmetric attributes of financial innovation activities, its effects on the aggregate productivity and CO2e is not the same. For instance, the positive shocks from financial innovation have the characteristics of higher research on the financial system, process innovation, organizational innovation, production innovation, risk minimization, investment diversifications, stable financial market, efficient allocation of resources, market expansions and competitive markets. All these factors help to ameliorate CO2e along with stimulating economic growth through promoting green financing and green investments (D'Orazio and Valente, 2019; Hall et al. 2017). Contrarily, the negative shocks of financial innovation possess the characteristics of the low ratio of organization and product innovations, financial constraints, high-risk value, low rate of investment, low profitability, and highly competitive pressure in the market, which results in disrupting financial innovation activities. More particularly, small and newly developed firms have to endure the adverse effects of high pressure of competition and financial constraints for sustaining productivity. For lowing the production cost during the economic downturn, these firms are persuaded to deploy fossil fuels for production, which tend to increase CO2e (Ullah et al., 2020).

In view of this discussion, the extended form of Cobb-Douglas production function is used:

$$Y = AL^{\alpha}K^{\beta}e^{\varepsilon} \quad (1)$$

Where Y= GDP per capita, A = total productivity (technology), L = labor input, K = capital input, and e = error term. Further, α and β represent the elasticities of output concerning labor and capital inputs, respectively. Following the work of Mtar and Belazreg (2020) and Belazreg and Mtar (2020), technology can be determined endogenously through innovation and financial innovation as:

$$A = \theta FI^{\tau}INN^{\sigma} \quad (2)$$

Where θ = time-invariant constant, FI = financial innovation, INN = innovation. Putting equation 2 in equation 1, the obtained equation can be presented as:

$$Y = \theta FI^{\tau}INN^{\sigma}L^{\alpha}K^{\beta}e^{\varepsilon} \quad (3)$$

In Eq. 3, FI and INN, are integrated along-with labor and capital. Innovation serves as a production technology input that boosts the process of economic growth by improving the production capacity efficiently and economies of scale (Ahmad et al. 2019). Likewise, FI also works as an active input that causes to increase the GDP growth by enhancing financial markets, functioning financial systems, empowering economic agents to expand and diversify the portfolios, and escalating the saving rate and capital accumulation ratio (Mishra and Pradhan, 2008; Levine 1997). To attain the GDP per capita, we divide both sides by *L* as follows:

$$\frac{Y}{L} = \theta e^{\varepsilon}\left(\frac{FI}{L}\right)^{\tau}\left(\frac{INN}{L}\right)^{\sigma}\left(\frac{K}{L}\right)^{\beta} \quad (4)$$

Environmentalists have a consensus on the proportional linkage between economic activities and CO2e, and these activities, without using the environmentally-friendly technologies, often stimulate the production process that increases the CO2e level (Aye and Edoja, 2017). Hence, the pollution function, as suggested by Ahmad et al. (2019), can be depicted as:

$$\mathrm{CO2e_t} = \mathrm{f(y_t)} \quad (5)$$

Where y_t indicates the per capita income. Moreover, we follow two fundamental assumptions in the current article. Firstly, environmental pollution does not stem from all kinds of physical capita during the production process. Secondly, the combustion of gas, oil, coal, and electricity is commonly believed in the accountable factors for CO2e. Therefore, physical capital can be decomposed into carbon-emitting capital (CEC) and non-carbon-emitting capital (NCEC), as equation 6 shows:

$$\mathrm{k_t} = \mathrm{k_{CEC}} + \mathrm{k_{NCEC}} \quad (6)$$

Hence, the production-based CO2e function can be expressed as:

$$\mathrm{CO2e_t} = \theta \mathrm{k}_{\mathrm{CEN(t)}}^{\gamma} \mathrm{fi}_{\mathrm{t}}^{\tau} \mathrm{inn}_{\mathrm{t}}^{\sigma} \mathrm{e}^{\varepsilon} \quad (7)$$

In Eq. 7, the functional form indicates that CO2e is dependent on capital, financial innovation, and technological innovation, while θ represents the ratio of CO2e resulting from the production process. Identifying the contribution of other variables in generating pollution, urbanization, and foreign direct investment (FDI) are incorporated into the model. Reason being, the integration of urbanization lies at the heart of enormous and extensive urban migration that has been occurred over the last two decades. In Asia, especially in the largest population economies, the migration of a lot of people has been observed form village to big cities, seeking jobs, better life facilities, developed infrastructure, more business opportunities, rapid industrialization, and economic prosperity. This huge influx of migrants has accelerated the deployment of residential and non-residential non-renewable energy while simultaneously intensifying the issue of CO2e (Cole and Neumayer, 2004).

After integrating the variables of FDI and urbanization (URBN) in the model, $k_{CEN(t)}$ is replaced with E_t (energy consumption) and write the equation as:

$$CO2e_t = \theta E_{(t)}^{\gamma} fi_t^{\tau} inn_t^{\sigma} FDI_t^{\delta} URBN_t^{\pi} e^{\varepsilon} \quad (8)$$

Even though the prior studies have suggested that energy combustion carried the significant direct association with the ratio of CO2e, however, the outcome based-on such integration has attracted the criticism on account of possible biasness (Jaforullah and King, 2017). To avoid such criticism, we replace E_t with FFC (fossil fuels consumption) in equation 8. Besides, to testify the EKC hypothesis, GDP along-with square of GDP are also included in the model as:

$$CO2e_t = \theta y_t^{\vartheta} (y^2)_t^{\omega} FFC_{(t)}^{\gamma} fi_t^{\tau} inn_t^{\sigma} FDI_t^{\delta} URBN_t^{\pi} e^{\varepsilon} \quad (9)$$

Next, we move towards the inclusion of positive and negative shocks of financial innovation in our equation. The positive shocks reflect an upsurge in financial innovation on account of economic boom, while the negative shocks are the reflection of the opposite scenario. Recognizing that no published work has yet explored the nexus between financial innovation (FI) and CO2e, it is apparently rationale that we erect a concept-based framework and dispense the theory-based reasons for the integration of FI variable in the pollution-model.

Thus, for incorporating the positive and negative shocks of financial innovation in our EKC equation, we impose the following restriction, as pe assertion of Schorderet (2003), on coefficients of financial innovation as:

$$\xi = \begin{cases} \psi^{+} & if\ \Delta fi_t > 0 \\ \psi^{-} & if\ \Delta fi_t < 0 \end{cases} \quad (10)$$

Where ψ^{+} = positive shocks and ψ^{-} = negative shocks of financial innovation. These variations (shocks) in financial innovation are included in the model as:

$$CO2e_t = \theta y_t^{\vartheta} (y^2)_t^{\omega} FFC_{(t)}^{\gamma} (I(\Delta fi_t > 0)\Delta fi_t)^{\psi^{+}} (I(\Delta fi_t < 0)\Delta fi_t)^{\psi^{-}} inn_t^{\sigma} FDI_t^{\delta} URBN_t^{\pi} e^{\varepsilon} \quad (11)$$

Where $(I(\Delta fi_t > 0)\Delta fi_t)^{\psi^+}(I(\Delta fi_t < 0)\Delta fi_t)^{\psi^-}$ is a utility function, defined as:

$$(\Delta fi_t > 0) = \begin{cases} 1 & \text{if} \quad \Delta fi_t > 0 \\ 0 & \text{if} \quad \Delta fi_t < 0 \end{cases} \tag{12}$$

$$(\Delta fi_t < 0) = \begin{cases} 0 & \text{if} \quad \Delta fi_t > 0 \\ 1 & \text{if} \quad \Delta fi_t < 0 \end{cases} \tag{13}$$

After the inclusion of positive and negative shocks of financial innovation, following Schorderet (2003), the equation can be depicted as:

$$CO2e_t = \theta y_t^{\vartheta}(y^2)_t^{\omega} FFC_{(t)}^{\gamma}(fi)^{\psi^+}(fi)^{\psi^-} inn_t^{\sigma} FDI_t^{\delta} URBN_t^{\pi} e^{\varepsilon} \tag{14}$$

Where $(fi)^{\psi^+}$ and $(fi)^{\psi^-}$ are positive and negative shocks of financial innovation, respectively. Likewise, the positive and negative shocks in technological innovations also enhance the environmental quality by curbing CO2e. Reason being, the increasing trends in technology leads increase the productivity level and profit that encourage the producers to deploy the green technologies. It results in decreasing the CO2e. On the contrary, the negative shocks in technological innovations reduces the productivity level and profits which build a pressure on producers to deploy dirty and cheap methods of production. It results in deteriorating the environment (Ahmed et al., 2019) Hence, we include the positive and negative shocks technologies and attain the final form of the model as:

$$CO2e_{it} = a_0 + a_1 y_{it} + a_2 {y^2}_{it} + a_3 FFC_{it} + a_4 fi_{it}^{+} + a_5 fi_{it}^{-} + a_5 ti_{it}^{+} + a_6 ti_{it}^{-} + a_7 FDI_{it} + a_8 URBN_{it} + \varepsilon_{it} \tag{15}$$

3.2. Data sources

To obtain the objectives of this study, we collect the data of proposed variables from different sources for the period 1987-2016 for BRICS (Brazil, Russia, India, China & South Africa) economies. The data for the variables of CO2e per capita, GDP per capita, total urban population (URBN) (a proxy for urbanization), patents (INN) (a proxy for innovation), foreign direct investment (FDI), and fossil fuels energy (FFC) is retrieved from the World Bank Indicators. Also, the definition and measurement unit of CO2e, GDP, URBN, INN, FDI, and FFC can be accessed at the site of the World Bank (https://data.worldbank.org/indicator). For financial innovation, M3/ M1, viz, the ratio of the aggregate money supply to narrow money (Dunne and Kasekende 2018) is used. The data for each indicator is retrieved from the annual reports and online data sources of *Banco Central do Brasil* for Brazil, The *Central Bank of Russian Federation* for Russia, *Reserve Bank of India* for India, the *People's Bank of China* for China, the *South African Reserve Bank* for South Africa. All variables are converted in logarithmic form, except the ones expressed in percentage terms.

3.3. Econometric Techniques

For empirical analysis, we perform the following four steps. First, the cross-sectional dependence (CSD) among the modeled data series is checked through employing Breusch-Pagan & Pesaran scaled LM, and Pesaran CD tests. Also, slope heterogeneity test is applied in order to check the potential heterogeneity. Second, second-generation panel unit root tests (SGUT), i.e., CADF and CIPS, are applied. Third, the Westerlund cointegration test (WCT) is used to assess the cointegration among the model parameters. Fourth, Common Correlated Effect Mean Group (CCEMG) and Augmented Mean Group (AMG) approaches are utilized to compute long-run estimates. Further, Fully-Modified Least Squares (FMOLS) method is utilized for checking the robustness of the findings at country level. Lastly, Dumitrescu-Hurlin panel causality test is used to check the casual nexus among the modeled variables.

3.3.1. Cross sectional dependence (CSD) and heterogeneity tests

The occurrence of cross-sectional interdependence and methodical limitations, as Zafar et al. (2019) argue, might be on account of global multiple interlinkages, viz, exports, imports, sports, financial and economic, across the countries. If the scholars do not control CSD accurately, the estimated coefficients may be biased and inconsistent, explained by Phillips and Sul (2003). To resolve this methodical exigency, we use CSD tests propounded by Pesaran (2004), expressed in the following equation:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N}\rho ij\right) \quad (16)$$

In Eq. 16, CD shows CSD, N denotes the number of cross-sections in panel data, T exhibits time period, and ρij represent CS correlation of error between i and j. LM test is adopted to capture CSD across the selected panel series, as shown below:

$$y_{it} = \theta_{it} + \pi_i x_{it} + \varepsilon_{it} \quad (17)$$

In Eq. 17, i and t indicate the CS in the series and time, respectively. Besides, the null hypothesis of LM tests is that the panel data series are cross-sectionally independent. Further, the heterogeneity test is also applied propounded by Pesaran and Yamagata (2008). This test is superior than the traditional heterogeneity test such as SURE (seemingly unrelated regression equation) since the later test becomes invalid to check the heterogeneity in the presence of cross-sectional dependency. Thus, the second-generation heterogeneity test is utilized and the equation of the test can be written as:

$$\widetilde{\Delta_{HT}} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}(\frac{1}{N}\tilde{S} - k)$$

$$\widetilde{\Delta_{AHS}} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}(\frac{1}{N}\tilde{S} - k)$$

Where $\widetilde{\Delta_{HT}}$ and $\widetilde{\Delta_{AHS}}$ indicate the delta tilde and adjust delta tilde, respectively.

3.3.2. Second generation unit root tests (SGUT)

The presence of CSD across the modeled series invalidates the application of traditional panel unit root tests, implying that the outcome of the first-generation unit root test may be misleading and biased in case of deep CS. Hence, we deploy SGUT (CADF and CIPS) for assessing that not a single series in the model is I(2). Following Pesaran (2007), we can write the equation as:

$$X_{it} = \sigma_{it} + \rho_i X_{it-1} + \theta_i T + \sum_{j=1}^{n} \pi_{ij} \Delta X_{i.t-j} + u_{it} \quad (18)$$

In Eq. 18, σ_{it} represents intercept, T demonstrates time, X_{it} denotes the regressors, Δ shows the difference operator, u_{it} denote the error term.

3.3.3. Westerlund cointegration test (WCT)

After getting confirmed that all variables are I(1), we apply Westerlund (2007) cointegration test to inspect the long-run association among variables and the equation can be exhibited as:

$$\Delta Y_{it} = \gamma_i d_t + b_i Y_{it-1} + \acute{\lambda}_i X_{it-1} + \sum_{j=1}^{pi} b_{ij} \Delta Y_{i.t-j} + \sum_{j=-qi}^{pi} Y_{ij} \Delta X_{i.t-j} + \varepsilon_{it} \quad (19)$$

In Eq. 19, d represents the residuals of the model, i denotes cross-sections, and t signifies, time period. Additionally, the test supposes "no-cointegration" among the modeled variables as the null hypothesis.

3.3.4. Long-run estimators

After establishing the long-run linkage among the modeled variables, we proceed with the effective techniques to estimate the long-run coefficients. To this end, common correlated effect mean group (CCEMG) and augmented mean group (AMG) approaches are utilized. Since the application of first-generation techniques may present misleading results in the presence of cross-sectional dependency and slope heterogeneity; therefore, we prefer to apply second-generation econometric approaches for robust results. Further, PFM-LS is also adopted to estimate the country level results for checking the robustness of the results (Chishti et al., 2020).

4. Results and discussion

Table 1 demonstrates that the constructs of the model carry the cross-sectional dependence as heterogeneity tests confirm, signifying that all the series are significant at the level of 1% and implying the invalidity of 1st generation unit root tests. In the similar vein, the outcome of slope heterogeneity test also indicates the invalidity of the application of traditional unit root tests which presents misleading results in the presence of heterogeneity. Thereby, 2nd generation unit root tests are applied to assure the stationarity of the selected variable in the model. As the outcomes are presented in Table 2, the null hypothesis of non-stationarity for all variables is not accepted at the first difference, which allows the establishment of the Westerlund panel cointegration tests. The results shown in Table 3 substantiate the presence of long-run association among the model parameters, validating the estimation of long-run coefficients.

Table 1: Cross-sectional dependence and heterogeneity tests

	BPLM	PsLM	BCsLM	PCD
CO2	82.84780 (0.0000)	15.17123 (0.0000)	15.08502 (0.0000)	5.320228 (0.0000)
Inn	110.3103 (0.0000)	21.31204 (0.0000)	21.22583 (0.0000)	3.896586 (0.0001)
FI	174.25 (0.0000)	76.7743 (0.0000)	76.7021 (0.0000)	22.6219 (0.0000)
URBN	282.2212 (0.0000)	59.75247 (0.0000)	59.66626 (0.0000)	16.79115 (0.0000)
FDI	74.67024 (0.0000)	13.34267 (0.0000)	13.25647 (0.0000)	8.099841 (0.0000)
FFC	121.8086 (0.0000)	23.88313 (0.0000	23.79692 (0.0000)	-1.178634 0.2385
Y	181.4107 (0.0000)	37.21056 (0.0000)	37.12435 (0.0000)	11.63002 (0.0000)
Y2	181.4107	37.21056	37.12435	11.63002
Slope heterogeneity test				
Model			$\tilde{\Delta}$	$\tilde{\Delta}_{Adjusted}$
			7.63***	7.01***

*** indicates the significance level at 1%.

Table 2: Second generation unit root tests

	CO2	INN	FI	FFC	FDI	URBN	Y	YSQ
CIPS								
I(0)	-2.095	-1.227	-2.006	-2.401	-1.803	-2.936	-1.252	-1.461
I(1)	-4.903***	-4.794***	-5.111***	-5.213***	-4.032***	-5.264***	4.763***	-4.215***
CADF								
I(0)	-1.961	-1.563	-1.753	-2.224	-1.472	-2.332	-2.128	-2.105
I(1)	-4.599***	-4.446***	-3.703***	-4.821***	-3.500***	-4.147**	-4.318***	-3.992***

Note: *** & ** indicate the level of significance at 1% and 5%, respectively.

Table 3: Westerlund cointegration test

Statistic	Value	Z-value	P-value
Gt	-8.739	-9.300	0.000
Ga	-19.211	-10.475	0.000
Pt	-7.713	-6.375	0.000
Pa	-13.217	-9.186	0.000

The outcomes of the long-run coefficient estimation are reported in Table 4. The outcomes indicate the impacts of positive and negative shocks of technological and financial innovations on the environmental quality. The upward shock to the financial innovation is found to improve the environmental quality. Commencement of the organizational innovations, stabilized expansion of the financial markets, ease in the financial constraints, and vast capital accumulation via financial innovation might be the possible reasons behind this impact. These processes encourage the green investment in cleaner technologies for achieving the green structural change (Sinha et al., 2017; Hall et al. 2017). In line with this argument, FDI and globalization have been driving the financial markets of the BRICS economies since the 1990s (Bose and Kohli, 2018). The financial innovation endeavors thus initiated have subsequently boosted the green investments to mitigate the CO2 emissions. For instance, the New Development Bank (NDB) approved $1.5 billion to finance the green and clean energy in 2016, while 4% of its total reserves are maintained for green investment to be utilized through different loan schemes.[3] Alongside this, (a) 11% of total loans in Brazil in 2016 is approved for green agricultural projects, (b) $226 million are disbursed by Russia bank for green financing program in 2013, (c) $48 million are allocated as a green fund by Development Bank of Southern Africa, and (d) *Green credit policy* and *Green Credit Guidelines* programs are issued by The People's Bank of China and China Banking Regulatory Commission in 2007 (Xing et al. 2020). While saying this, the study outcomes also show that the downward shock to the financial innovation is found to deteriorate the environmental quality. A possible explanation of this impact is that the sluggishness of the financial innovation during economic downturns tends to increase the financial instability, the probability of risk, and constraints the financialization process, and these occurrences disrupt the process of green investment. Consequently, firms divert from using the green technologies. Moreover, the results also reveal that the downside environmental risk of the negative shock to financial innovation is higher, compared to the betterment of environmental quality arising out the negative shock to financial innovation. From the policymaking perspective, this downside risk of the financial innovation needs the attention of the policymakers.

Table 4: The estimates of AMG and CCEMG methods

	AMG estimates	P-value	CCEMG estimates	P-value
FI+	-0.061***	0.000	-0.084***	0.000
FI-	0.194***	0.000	0.178***	0.000
INN+	-0.103**	0.021	-0.052***	0.000
INN-	0.006	0.134	0.009	0.115
FFC	0.267***	0.000	0.583***	0.000
FDI	-0.036***	0.000	0.088**	0.012
URBN	-0.293**	0.000	-0.169***	0.016
Y	0.802***	0.000	0.917***	0.000
YSQ	-0.136**	0.000	-0.103***	0.000

[3] https://www.ndb.int/president_desk/ndb-president-60-funding-will-renewables/

Note: + & - denote the positive and negative shocks, respectively.
***, **, and * represents the significance level at 1%, 5%, and 10%, respectively.

Moving onward, the environmental impact of the shocks to technological innovation is analyzed. The study outcomes show that the positive shocks to technological innovation helps in improving the environmental quality, whereas the negative shocks to technological innovation deteriorates the environmental quality. It can be assumed that a positive shock to the technological innovations might lead to a rise in the research and development towards the development of cleaner technologies, and hence, the environmental degradation might come down. On the other hand, a slump in the technological innovation might disrupt the development and deployment of the cleaner technologies, thereby resulting in the rise in environmental degradation. The study outcomes conform to this argument. However, this particular segment of the results also reveals that the negative environmental impact arising out the negative shock to the technological innovations is less, compared to the positive environmental impact arising out the positive shock to the technological innovations. It gives an indication that the environmental quality takes time to correct itself, following the slump in the technological innovations. This also indicates the steady nature of the innovation endeavors in the BRICS countries, which have lower possibility of facing a slump. This might be the reason behind the negative environmental impact is insignificant. This result is in the line the outcomes of Churchill et al. (2019) for G-7 economies, Ahmad et al. (2019) for OECD economies, Mensah et al. (2018) for OECD economies, and Shahbaz et al. (2018) for France.

An indication of the economic growth trajectory being attained by the BRICS countries can be found in the environmental impact of their energy consumption pattern, which is majorly driven by the fossil fuel-based energy solutions. Continuous usage of these solutions has resulted in a rise in the CO_2 emissions in these countries, and it is reflected in the study outcomes. This finding supports the prior results of Qingquan et al. (2020) for selected Asian countries, Dar and Asif (2017) and Sinha and Shahbaz (2018) for India. In order to bring forth a change in this energy consumption pattern, a policy intervention is necessary, and it should be in terms of embarking on the green innovations. Given these nations are emerging in nature, development of the technological capabilities might take time, and hence, as a short-term solution, these nations might be importing the cleaner technologies from the developed nations. To achieve this, these nations might be utilizing the FDI route. Therefore, the FDI is expected to exert a positive environmental externality. The study outcomes conform to this argument. This outcome is coherent with the assertions of Shao et al. (2019) for BRICS, and Hille et al. (2019) for Korea. In order to complement this innovation endeavors, the rural-urban migration will also need a policy intervention. With the rise in the technological and financial innovations, the urban centers might experience a rise in the job opportunities, which will be inevitably followed by a rise in the urban population. In absence of proper urban management policies in place, the urban centers might start facing the issues of rising emission levels. So, the policymakers in these countries have started making the urbanization process environmentally sustainable. The study outcome reflects this in terms of the impact of urbanization on the CO_2 emissions. The *Neo-Urbanization policy* in China (Anwar et al., 2021) and *Smart City* projects in India (Fromhold-Eisebith and Eisebith, 2019) the two examples of such initiatives. Findings of similar nature are reported by Qingquan et al. (2020) for Asian economies, and Haseeb et al. (2018) for BRICS economies. Lastly, the study outcome confirms the validity of the EKC hypothesis. The presence of the turnaround points within the sample range shows the perceivable sustenance in the economic growth pattern. While saying this, it should also be noted that the turnaround points are in the close vicinity to the upper bound of the sample. Hence, in absence of proper policy intervention, this equilibrium might not be stable. This evidence extends the finding of Sinha and Sen (2016).

The country-specific outcomes reported in Table 5 show that the BRICS member countries follow a nearly similar pattern in case of all the model parameters. Except for Russia, all the other countries have shown the evidence of the presence of the EKC hypothesis. Figure 1 illustrates the positive and negative shocks in financial innovation.

For checking the robustness of the study outcomes, Dumitrescu Hurlin panel causality test is employed. The results reported in Table 6 confirm the unidirectionality from the shocks in financial and technological innovation to CO_2 emissions. Apart from that, the other model parameters also demonstrate unidirectional causality towards the CO_2 emissions. This segment of the outcomes also confirms the absence of possible endogeneity in the model.

Table 5. Country-specific long-run outcome

	FI+	FI-	INN+	INN-	FFC	FDI	URBN	Y	YSQ
Brazil	-0.136 (0.001)	0.170 (0.000)	-0.249 (0.006)	0.075 (0.086)	0.482 (0.003)	-0.164 (0.072)	-0.745 (0.062)	0.714 (0.013)	-0.154 (0.000)
Russia	-0.046 (0.000)	0.072 (0.008)	-0.174 (0.000)	0.003 (0.145)	0.793 (0.000)	-0.081 (0.092)	-0.304 (0.104)	0.504 (0.000)	0.115 (0.000)
India	-0.025 (0.053)	0.095 (0.003)	-0.003 (0.184)	0.001 (0.352)	0.666 (0.042)	-0.100 (0.005)	-0.971 (0.008)	0.395 (0.000)	-0.094 (0.000)
China	-0.177 (0.009)	0.216 (0.000)	-0.099 (0.007)	0.011 (0.106)	0.626 (0.027)	-0.206 (0.007)	-0.814 (0.000)	0.376 (0.000)	-0.126 (0.000)
South Africa	-0.261 (0.015)	0.348 (0.006)	-0.184 (0.003)	0.064 (0.214)	0.538 (0.001)	0.006 (0.000)	-0.489 (0.004)	0.603 (0.032)	-0.103 (0.024)

Note: + & - denote the positive and negative shocks, respectively.

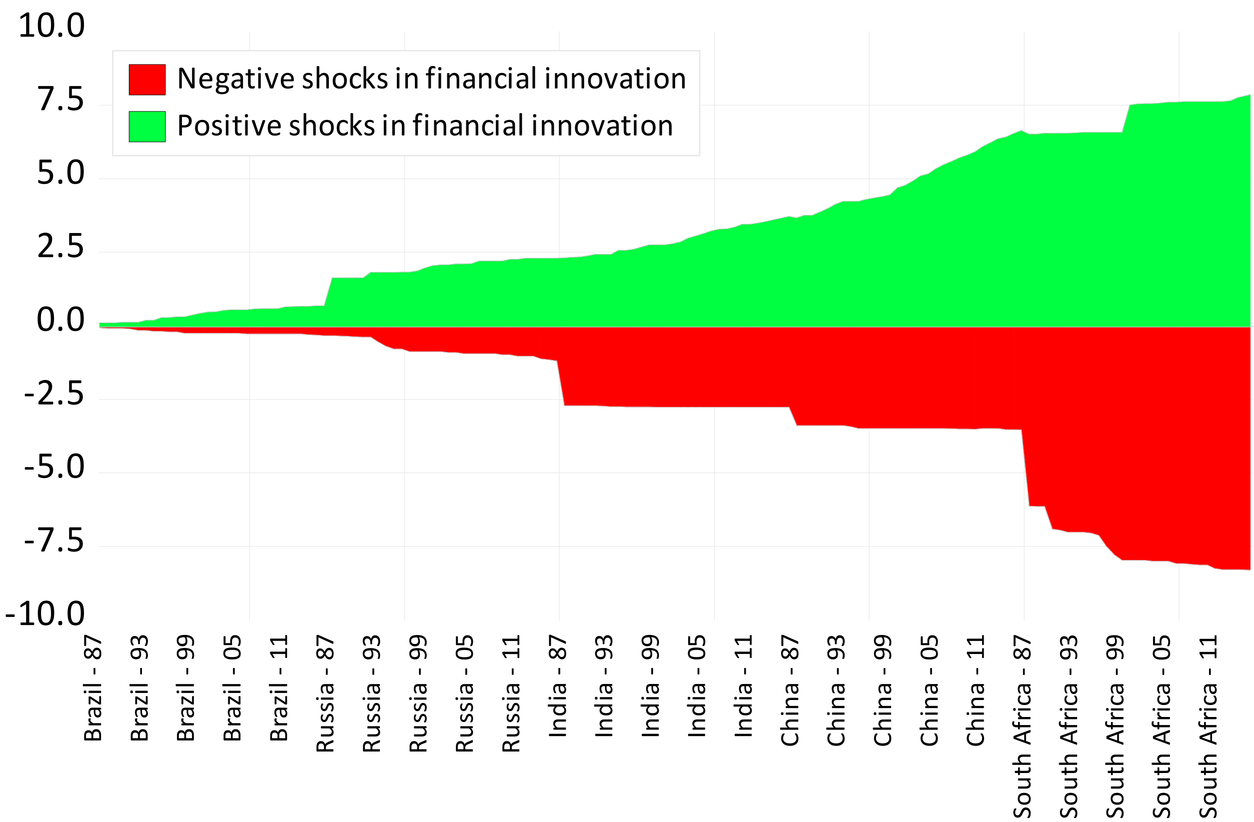

Figure 1. The positive and negative shocks in financial innovation

Table 6. Dumitrescu Hurlin panel causality test

Null Hypothesis	W-Stat.
FI+ → CO2e	6.145***
CO2e → FI+	1.6038
FI- → CO2e	4.937***
CO2e → FI-	1.481
INN+ → CO2e	7.765***
CO2e → INN+	1.524
INN- → CO2e	2.898
CO2e → INN-	0.802
FFC → CO2e	6.185***
CO2e→ FFC	1.404
FDI → CO2e	6.090***
CO2e → FDI	0.474
URBN → CO2e	5.975***

$CO2e \rightarrow URBN$	0.885
$Y \rightarrow CO2e$	4.886**
$CO2e \rightarrow Y$	1.445
$YSQ \rightarrow CO2e$	5.115***
$CO2e \rightarrow YSQ$	1.065

Note: *** & ** show the significance level at 1% and 5%, respectively.

5. Conclusion and policy recommendations

By far, the environmental impact of the shocks to financial and technological innovations is analyzed for the BRICS countries. The study outcomes show that the negative shocks to financial and technological innovations exert negative environmental impact, whereas the positive shocks to financial and technological innovations exert positive environmental impact. These results are utilized to develop a policy framework for the BRICS countries.

5.1. Core policy framework

As the BRICS countries are developing their technological capabilities, these projects might require funding support from the respective governments. One of the major reasons being the risks associated with these projects, because of which these projects might not be able to attract private investments. However, the public investment might cause a fiscal burden on the governments. In order to solve this problem, the policymakers might take a phase-wise policy design approach, which can boost the financialization of these projects, while reducing the downside risk of the financialization. During the first phase, the policymakers might consider importing the clean technology solutions from the developed nations via the FDI route, and make those solutions available to the industrial sector at a pro-rata rate. The firms can avail these solutions against credit from the financial institutions. However, the interest on the credits might be discriminatory based on the carbon footprint of the firms, i.e., firms with higher carbon footprint will have to bear higher rate of interest. In order to push the firms towards embracing these solutions, the policymakers might increase the price of fossil fuel-based energy solutions progressively. This will discourage the firms to use the fossil fuel-based energy, and the demand for renewable energy solutions might rise gradually. In order to cater to the demand of the renewable energy solutions and reduce the carbon footprint, the firms will start availing the cleaner technology solutions. This innovative financialization process might help in generating a sustained stream of interest income, without causing harm to the cash flow of the firms. This income might be diverted towards financing the technological innovation and green energy discovery projects.

Once this phase is stabilized, the policymakers might start the process of import substitution for reducing the importing of cleaner technologies. As the domestic players might have developed the innovation capabilities during the first phase, the rising demand of technological innovations and renewable energy solutions should be catered by the domestic players. In this way, the dependence on the imported technological solutions will be reduced, which will help these solutions to be free from the shocks arising in the international markets. This will help reducing the downside risk of the technological innovations. As these two phases are operational, these countries will be able to make a steady progression towards the attainment of SDG 7. Moreover, the environmental impact of these solutions will be visible in the betterment of the environmental quality, and this will help these countries in progressing towards the attainment of SDG 13.

5.2. Tangential policy framework

While the core policy framework is developed directly from the study outcomes, the tangential policy framework might help the policymakers in sustaining the framework. Once the financialization process is stabilized, these nations might start experiencing a rise in the job opportunities. Proper urban management facilities and expansion of the existing urban centers might help these countries in accommodating the rising migration of people from the rural areas in search of job opportunities. Once this policy-level facilitation is carried out, the living standard of the citizens might improve, both economically and ecologically. This will help these countries in making a progression towards the attainment of SDG 8, i.e., decent work and economic growth.

5.3. Limitations and future directions

The policy framework recommended in the study has considered the shocks to financial and technological innovations, while choosing FDI and urbanization as the contextual parameters. However, the context of the BRICS countries might be explained with a wider array of the policy parameters, and that can be considered as a limitation of the study. Saying this, it is also necessary to mention that the policy framework recommended in the study has the aspects of flexibility and generalizability, and owing to this reason, this framework can be used as a benchmark for the other emerging economies. The flexibility of the framework allows the policymakers from the other emerging economies to modify it in accordance with their contextual settings, while keeping the policy objective intact. There lies the contribution of the study. Future studies on this aspect can be carried out by considering the spatial dimensions of trade and the shocks to labor market, as these dimensions might allow the future researchers to discover the impact of international relations and the domestic labor market in shaping the nature of environmental quality.

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Authors' contributions:
Muhammad Zubair Chishti: Conceptualization, Draft Writing, Methodology, Econometric Analysis
Avik Sinha: Supervision**,** Draft Writing, Revision

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