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Green innovation-green growth nexus in BRICS: Does financial globalization matter?

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A B S T R A C T

Green growth is a novel theme, gaining prominence in the current era. Therefore, this study investigates the impact of green innovation and financial globalisation on green growth in the BRICS (Brazil, Russia, India, China and South Africa) economies. The study employs the CS-ARDL model for the analysis. The findings confirm that the long-run estimates of environmental innovations and patents are positively significant, ensuring that environment-related technologies are helpful in attaining green growth in the BRICS economies. Moreover, the estimates of financial globalisation are significantly positive, suggesting that a rise in financial globalisation leads to an increase in green growth in the BRICS economies. Our findings imply that, to promote green growth in the BRICS economies, policymakers should focus on R&D activities that can encourage the development of green innovations.

Introduction

BRICS is an acronym for Brazil, Russia, India, China, and South Africa, which are five large and emerging economies of the world. These economies are prominent among the developing economies of the world because of their impressive rate of economic growth and efforts to attain sustainable development (Zhang et al., 2022). However, the challenges and problems faced by these countries in attaining sustainable economic development include global warming, health concerns, maintaining high economic growth, and the search for clean and green energy sources. Nevertheless, these economies have abundant natural resources and are equipped with the latest technologies (Li et al., 2022). among them, China and India have a large population, allowing them to take advantage of cheap labour, and produce goods and services at a low cost using labour-intensive production techniques. Meanwhile, the remaining three countries, Russia, Brazil, and South Africa, are gifted with minerals and natural resources, which they export to other countries.

Even though the idea of a green economy is not new, dating back to the early 1970s, it gained popularity and prominence in 2009, when international organisations directed the global community to follow sustainable policies that could decouple economic growth and CO_2 emissions. In this regard, following the footprints of North America and Europe, BRICS economies, particularly China and India, also started moving towards green growth via an increasing share of renewable energy sources in their total energy mix (Gu et al., 2018; Zhao et al., 2021b).

Green growth simply implies that production and demand-driven emissions should be controlled by using green technological innovations, to help attain 'green production and supply chains' (Ullah et al., 2021). According to Mensah et al. (2019), the important determinants of green growth include environmental technologies associated with the production and distribution of energy. It is widely recognised that green growth can be used as a viable solution to save energy and mitigate CO_2 emissions (Guo et al., 2017), and as a reasonable action plan to control environmental damage (Sandberg et al., 2021). To boost production efficiency, green growth depends mainly on technological innovation. Green technology can serve as an important tool to attain green economic growth (Sohag et al., 2019), and its implementation can also help decrease CO_2 emissions (Chen et al., 2022).

Technical efficacy can play a vital role in a steady and successful CO_2 mitigation strategy (Gielen et al., 2019); this fact is also supported by other studies (Usman et al., 2021; Wei & Ullah, 2022). Other studies have found that renewable energy technologies are an

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important factor in reducing CO_2 emissions (Lin & Zhu, 2019; Sarkodie & Strezov, 2018). Technical efficiency combined with renewable energy technologies is vital in the production of clean and green energy with lower external costs and, consequently, lower carbon emissions (Alam & Murad, 2020). From the above discussion, we can deduce that technological innovation can help reduce energy consumption by increasing energy efficiency (Banerjee & Murshed, 2020).

In the meantime, an increasing rate of economic growth has brought the issues of resource scarcity and environmental degradation to the fore, shifting the focus of policymakers from the conventional concept of economic growth to the modern concept of sustainable development. In contrast to traditional economic growth theorists, proponents of sustainable development have turned their attention toward technological change as a catalyst to accomplish green transformation (Aghion et al., 2016), because traditional economic growth theories rely on laisser-faire equilibrium, which leads to environmental degradation (Acemoglu et al., 2016). However, Aghion et al. (2016) highlight the significance of environment-related taxes and patents as the major driving forces behind technological change that can mitigate CO_2 emissions.

In this era of globalisation, technological innovation in one economy can be adopted by other economies because of spillover effects (Pineiro-Chousa et al., 2019). Globalisation is another term for financial freedom and liberalisation, which is used to attract research and development activities induced by foreign direct investments (Dauvergne, 2008). Globalisation enables an increase in trade activities, which influences environmental quality through two effects, i.e., scale and composition effects (Shahbaz et al., 2016). On the other hand, a well-functioning and vibrant financial sector provides easy access to a wide variety of financial products and services that can help promote R&D activities, boost technological innovations, and enhance renewable energy projects that can significantly improve environmental quality (Murshed, 2020; Akadiri & Adebayo, 2022). Similarly, financial globalisation increases efficient and eco-friendly green innovations via the technique effect, thereby improving green growth.

In light of the above discussion and due to the emergence of the BRICS economies at the world economic and political stage and their role in consuming natural resources of the world and affecting environmental quality, we aim to examine the impact of green technological innovation and financial globalisation on the CO_2 emissions of these economies over the period 1993−2019. The literature argues that financial globalisation and green innovation are both key factors in green growth. Both are expected to have a significantly positive effect on green growth. To the best of our knowledge, this is the first study to capture the influence of green technological innovation and financial globalisation on CO_2 emissions in the context of the BRICS economies. The roles of green innovation and financial globalisation have not been extensively explored in the current literature. Previous studies have reported inconclusive results. Moreover, despite sufficient effort, we are unable to find any study that explores the short-term impact of green innovation and financial globalisation on green growth in the BRICS economies. Global evidence, most specifically for the BRICS economies, is missing in the literature.

Further, most of the earlier studies have overlooked cross-sectional dependence (CD), which is not an option in this era of globalisation. However, in this study, we have addressed the issue of CD by applying a novel technique known as the cross-sectional augmented ARDL (CS-ARDL) model, which is a more robust technique than other techniques. Finally, while most past studies have focused only on long-run estimates, we have considered short- run estimates as well. Our study employs the CS-ARDL approach to explore the impact of financial globalisation and green innovation on green growth. This technique has been used for several reasons. First, it provides efficient long- and short-run estimates. Second, it is used to control cross-sectional dependence among the selected economies of the sample.

Our study fills the existing gap in green growth literature in the following ways. First, the prevailing literature on the nexus between green innovation and green growth is limited. Additionally, we find very few studies exploring the association between financial globalisation and green growth. Thus, the first contribution of our study is that it explores the combined impact of green innovation and financial globalisation on green growth. The second contribution is that our study utilises the CS-ARDL approach to provide result estimates for long- and short-run periods. The findings of our study will provide significant policy implications that may help policymakers in BRICS economies design policies that ensure the long-term sustainability of green growth.

The remainder of this paper is organised as follows: a literature review is provided in Section 2; details about the data, model, and method are explained in Section 3; results and discussion are given in Section 4; and the conclusion and implications are summarised in the last section.

Literature review

Green growth is defined as growth that occurs due to a reduction in environmental and ecological security risks, and an upsurge in human well-being (Jänicke, 2012). Economists have widely debated that green innovation is a fundamental source of green growth. For the first time, Schumpeter (1934) explored the nexus between technology innovation and economic growth and indicated that the former boosts the evolutionary process of the latter. Aghion & Howitt (1992) reported that R&D in green technology has a positive impact on economic development. Jiang et al. (2020) argue that R&D stimulates innovations that promote green economic growth. Ahmed et al. (2022) further add that innovation diffusion plays a prominent role in the sustainability of economic development. However, owing to emerging environmental and resource challenges, the research focus has been gradually shifting towards attaining green growth in a more eco-friendly manner, and technological innovation is now converging towards sustainable green innovation (Hsu et al., 2021; Li et al., 2021).

Two viewpoints emerged from the literature regarding the influence of green innovation on green growth. First, green technologies and innovation contribute to green growth by reducing production waste and pollution emissions (Ghisetti & Quatraro, 2017). By developing eco-friendly green technologies, organisations can reduce energy consumption and pollution emissions, enabling green production to enhance green growth. Additionally, green innovation and technologies help in the reutilisation of production waste and recycling (Zhang et al., 2019; Zhao et al., 2021a). Second, green technologies are considered constraints on green growth. It is justified as the technological innovations produce a rebound effect that intensifies energy consumption and pollution, ultimately shrinking the level of green growth (Zhang et al., 2018). Another justification is that enterprises completely ignore environmental concerns, and pursue green innovation only for profit maximisation, by saving capital and labour. This may result in increasing environmental pollution and resource wastage, which is detrimental to green growth (Zhang & Vigne, 2021). Hence, according to the second argument, green innovation does not always result in green growth. Therefore, in view of reports of both positive and negative impact, the findings of the existing literature on the relation between green innovation and green growth, are inconclusive. Thus, we hypothesize:

Hypothesis 1. ***There is a positive relationship between green innovation and green growth.***

Financial globalisation, a determinant of liberalisation, financial openness, and digital financial inclusion, increases the attractiveness of R&D, and tends to enhance green growth (Chen et al., 2021; Huang et al., 2021; Kose et al., 2008). Chinese firms hold cash to maintain financial stability and financial constraints (Lei et al., 2021). Cash flows are positively associated with financial constraints (Deng & Zhao, 2022). There is considerable debate among researchers and policymakers regarding the impact of financial globalisation on economic growth. Financial globalisation influences green growth through three channels (Ulucak et al., 2020). The 'scale effect' channel describes how financial globalisation expands economic activities, leading to increased consumption of fossil fuels, which ultimately reduces environmental quality, thereby diminishing green growth. In contrast, the 'technique effect' channel states that by increasing efficient and eco-friendly green innovation, financial globalisation may reduce pollution emissions, thereby intensifying green growth. The literature discusses another channel, the 'composition effect', which describes an inconclusive association between financial globalisation and green growth. According to this effect, financial globalisation exerts both positive and negative effects on green growth depending on output composition (Bhattacharya et al., 2016).

Jiang & Chang (2022) noted that financial globalisation positively influences the host economy's green growth. In contrast, Song et al. (2015) reveal that the introduction of financial globalisation in the industrial sector may reduce the productivity of pollution-intensive enterprises, thereby reducing green growth. Wang et al. (2021) report a negative influence of financial globalisation on the industrial sector's green productivity due to a spillover effect. Some studies argue that financial globalisation causes technological innovation that enhances green transformation in the host economies' industrial sector, thereby promoting green growth (Li et al., 2019). Additionally, Lin et al. (2019) reported a positive impact of financial globalisation on green productivity in Taiwan, Macao, and Hong Kong. Helen (2017) reported a positive effect of financial globalisation on domestic consumers, which tends to enhance green growth. Therefore, the literature provides inconclusive evidence of the impact of financial globalisation on green growth. Accordingly, we hypothesise as follows:

Hypothesis 2. ***There is a positive relationship between financial globalisation and green growth.***

Data and methodology

Variables and data description

This study investigates the impact of green innovation and financial globalisation on green growth in the BRICS economies from 1993 to 2019. Table 1 presents detailed information related to definitions, symbols, descriptive statistics, and data sources. Environmentally adjusted multifactor productivity was used to measure green growth. Standard literature (Rodríguez et al., 2018; Hao et al., 2021) also employs environmentally adjusted multifactor productivity to denote green growth. As described in the literature, green innovation is the most important determinant of green growth.

Thus, following the studies conducted by Danish & Ulucuk (2020) and Wei et al. (2022), this study adopted two variables. Environmental innovation is a proxy measure for green innovation, taken as the percentage of environment-related technologies in all used technologies. Following Ullah et al. (2021), we used technological innovation for the robustness of the results. Another major variable used in our study is financial globalisation, which is measured using the financial globalisation index. Following studies, such as Nasreen et al. (2020) and Ulucak et al. (2020), we argue that financial globalisation is a major determining factor of environmental performance that positively influences green growth. Furthermore, following Wei et al. (2022), we use government size and human capital as control variables. Government spending is measured as the percentage of the general government final consumption expenditure in Gross Domestic Product (GDP). Finally, human capital is measured as the average number of years of primary schooling. Data for this study were taken from the OECD, the KOF Swiss Economic Institute, Barro and Lee, and the World Bank.

Model and methods

Technological advancement is an important way to improve energy efficiency, which, in turn, helps mitigate carbon emissions; however, the flip side of the story is that an increase in energy efficiency exerts pressure on natural resources and energy demand, which causes CO_2 emissions to rise, due to the rebound effect (Wang and Wei, 2019). In general, while the development of technology has proved to be vital in reducing CO_2 emissions, it may also activate the rebound effect, thereby spurring emissions (Gu et al., 2019). Thus, the role of technological development in mitigating CO_2 emissions by increasing energy efficiency, is marginal (Sohag et al., 2019). Similarly, financial globalisation raises technological innovation and financial development by increasing economic development (Mishkin, 2007). Financial globalisation is considered a determining factor of financial openness, which raises R&D activities in host economies (Petit, 2010). As discussed, an increase in financial globalisation produces three types of effects: composition, technique, and scale. It contributes to increasing the technique and composition effects by providing funds for investment into eco-friendly projects that subsequently ensure green growth.

Following Mensah et al. (2019) and Ulucak et al. (2020), we constructed the following model to analyse the impact of environment-related technologies and financial globalisation in improving environmental quality by promoting green growth and production-driven emissions.

$$GG_{it} = \eta_0 + \eta_1 GI_{it} + \eta_2 FG_{it} + \eta_3 GS_{it} + \eta_4 HC_{it} + \varepsilon_{it} \tag{1}$$

Green growth (GG) is dependant on green innovation (GI), financial globalisation (FG), government spending (GS), human capital (HC), and randomly distributed error terms (ε_{it}). Green growth is the growth of environmentally adjusted multifactor productivity. This is measured by the ability of a country to generate income from

Table 1
Definitions and data descriptions.

Variable	Definitions	Mean	Median	Max	Min	S.D	Skewness	Kurtosis	JB	Prob.	Sources
GG	Environmentally adjusted multifactor productivity	5.049	4.891	13.13	−6.233	3.351	−0.482	3.856	9.335	0.009	OECD
EI	Development of environment-related technologies,% all technologies	9.130	9.160	16.80	3.730	2.556	0.257	2.500	2.890	0.236	OECD
Patent	Patent applications, total (residents and nonresidents)	10.21	10.14	14.24	8.052	1.361	1.175	4.381	41.78	0.000	World bank
FG	Financial globalisation index	46.74	46.00	75.00	20.00	13.97	0.011	2.072	4.849	0.089	KOF Swiss Economic Institute
GS	General government final consumption expenditure (% of GDP)	16.24	16.97	21.06	9.802	3.182	−0.677	2.229	13.65	0.001	World bank
HC	Average years of primary schooling, age 15+, total	4.895	5.117	7.062	2.422	1.054	−0.572	2.899	7.416	0.025	Baroo and lee

available resources, while considering the use of natural resources and the production of environmental outputs. Green innovation is useful in the transition of economic structures and helps to stimulate green growth. We expect the estimate of η_1 in Eq. (1) to be positive. The literature notes that financial globalisation is an important determinant of green growth, and thus, we expect the estimate of $\eta_2$to be positive. Finally, the estimates of η_3 and η_4 are positive. Specification (1) is a long-term equation, whereas this analysis is interested in both, short- and long-run estimates. Therefore, we must specify the above equation in the format of error correction, as shown below:

$$\begin{aligned}\Delta GG_{it} = C_i \\ &+ \lambda_i\left(GG_{it-1} - \beta_i X_{it-1} - \Upsilon_i C_{it-1} - \phi_{1i} GG_{t-1} - \delta_2 \overline{X}_{t-1} - \pi_2 \overline{C}_{t-1}\right) \\ &+ \sum_{j=1}^{p-1} \theta_{ij} \Delta GG_{it-j} + \sum_{j=0}^{q-1} \eta_{ij} \Delta X_{it-j} + \sum_{j=0}^{q-1} \tau_{ij} \Delta C_{it-j} \\ &+ \eta_{1i} \Delta GG_t + \eta_{2i} \Delta \overline{X}_t + \eta_{3i} \Delta \overline{C}_t + \varepsilon_{it}\end{aligned} \tag{2}$$

Specification (2) is an augmented version of the PMG-ARDL model and is known as CS-ARDL model first presented by Chudik & Pesaran (2013). Most previous studies have relied on first-generation panel data estimation techniques, such as POLS, DOLS, and FMOLS, which have many shortcomings, and provide biased and unpredictable results (Danish & Ulucuk, 2020). However, CS-ARDL has several advantages over these estimation techniques. First, it can account for the integrating properties of the model variables; therefore, it can handle an equation with a mixture of I(0) and I(1) variables, thereby providing robust results in the case of non-stationary series. Moreover, the problem of CD, if ignored, provides biased estimates, however, the CS-ARDL model is capable of efficiently handling this issue, as well as that of slope heterogeneity (Chudik & Pesaran, 2013). Another advantage of this technique is that it can provide both long- and short-run estimates, with no extra effort, and by analysing only one equation. Further, the addition of a short-run dynamic process can solve the endogeneity problem. Finally, it performs efficiently in case of small sample sizes.

Results and discussion

As this study uses panel data, it is compulsory to check the CD properties of the data. For this purpose, we use Pesaran's (2004) CD test. Table 2 shows the results of the CD test. The results reveal that all economies are CD, as shown by the statistically significant coefficient estimates. This shows that any variation in one economy will definitely influence the others in the sample. In the next step, it is mandatory to detect the stationarity properties of the data. In this regard, we applied the IPS, LLC, and ADF unit root tests. These tests efficiently detect the unit root properties of panel data. In Table 3, the results of the LLC unit root test show that GG, EI, FG, and HC are I(0) stationary variables, whereas FS is an I (1) stationary variable.

Table 2
Cross-sectional dependence.

	GG	EI	FG	GS	HC
Pesaran's test	2.770**	4.628***	6.303***	−0.222	4.222***
Prob.	0.005	0.000	0.000	0.824	0.000
Off-diagonal elements	0.212	0.318	0.416	0.250	0.410

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

However, the results of the ADF and IPS tests reveal that GG, EI, and HC are I(0) stationary variables, whereas FG and FS are I (1) stationary variables. To test the long-run co-integration among the variables, we used the Westerlund panel co-integration test. Table 4 presents the results of the panel co-integration tests, revealing that a long-run co-integration link exists among the selected variables of the model.

The panel estimates of the green growth model are presented in Table 5. The results show that the effect of environmental innovation is positive and significant for long-term green growth. The table shows that a 1 percent increase in environmental innovation tends to enhance green growth by 0.065 percent in the long term. The application of CS-ARDL and PMG-ARDL confirm the positive influence of environmental technologies on green growth in the BRICS economies. Danish & Ulucuk (2020) and Liu et al. (2020) found similar findings. Our empirical findings support hypothesis (1). The promotion of technological innovation may help reduce carbon emissions by enhancing the efficiency of production techniques and altering energy structures. Advanced environmental measures promote the development of technologies, particularly environment-related ones. This finding is also supported by Wang et al. (2021), who noted that the development of green technologies in the energy sector helps increase the demand for renewable energy. This, in turn, increases renewable energy intensity and green growth. Such advantageous effects may appear gradually in BRICS nations. On one hand, the development of energy technology greatly improves the efficiency of production equipment; on the other hand, the promotion of environment-related energy innovations may improve environmental sustainability. During the development of green technologies, replacing fossil fuels with clean energy sources may become possible, which will help mitigate carbon emissions. Another possible reason is that innovation plays an essential role in promoting and developing technological processes that reduce energy consumption by promoting energy conservation, in turn, improving green economic development.

Financial globalisation positively and significantly influences long-term green growth. A 1 percent increase in financial globalisation leads to a 0.071 percent increase in green growth. Our empirical findings support hypothesis (2). This finding is also supported by the "pollution halo" hypothesis (Xu and Deng, 2012), which noted that financial inflow brings in new technologies to host nations and promotes green growth. This finding implies that financial globalisation can serve as an essential driver of importing clean technologies from advanced economies. This may instigate technique and composition

Table 3
Panel unit root test.

	LLC			ADF			IPS		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision	I(0)	I(1)	Decision
GG	−4.063***		**I(0)**	−5.994***		**I(0)**	−3.752***		**I(0)**
EI	−1.370*		**I(0)**	−2.367***		**I(0)**	−2.411**		**I(0)**
Patent	−2.365***		**I(0)**	−2.302*		**I(0)**	−2.023*		**I(0)**
FG	−1.749**		**I(0)**	0.188	−6.903***	**I(1)**	−1.477	−4.110***	**I(1)**
GS	−0.021	−2.663***	**I(1)**	0.014	−2.302***	**I(1)**	−2.015	−4.270***	**I(1)**
HC	−2.981***		**I(0)**	−2.118*		**I(0)**	−2.306×8		**I(0)**

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 4
Westerlund panel cointegration.

Statistic	Gt	Ga	Pt	Pa
Value	−3.566**	−8.768	−7.991***	−17.09*
z-value	2.213	1.881	2.637	1.447
P-value	0.014	0.970	0.004	0.074

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

effects in emerging economies, allowing them to transform their economies and rely more on 'clean' sectors (Ulucak et al., 2020). Our findings support those of Kihombo et al. (2022) and Wang et al. (2022), confirming the positive role of financial globalisation in the green economy. They confirmed that the technique effect dominates the scale effect in these economies. However, these results are not supported by previous studies, such as Farouq et al. (2021) and Shahzad et al. (2022).

The findings show that government spending produces significant and positive improvements in green growth in the long run. It shows that a 1 percent increase in government spending tends to improve green growth by 0.337 percent in the long run. However, the impact of human capital on green growth is statistically insignificant in the long term. The short-run findings show that the impacts of environmental innovation, financial globalisation, and human capital on green growth are insignificant. However, government spending reports a statistically significant increase in green growth in the short term. The findings of the variable-based and method-based robust models are consistent in magnitude and sign. The ECM term is negative and statistically significant, revealing a possibility of convergence towards equilibrium (in case of any disequilibrium). These findings

Table 5
Panel estimates of green growth.

Variable	Basic model CS-ARDL Coefficient	t-Stat	Variable based robustness CS-ARDL Coefficient	t-Stat	Method based robustness ARDL-PMG Coefficient	t-Stat
Long-run						
EI	0.065**	2.056			0.062**	2.225
PATENT			0.492*	1.904		
FG	0.071**	2.540	0.085***	3.343	0.066***	5.115
GS	0.337*	1.722	0.420**	2.022	0.307**	2.420
HC	0.328	0.483	0.968	1.392	0.876***	2.307
Short-run						
D(EI)	0.004	0.045			0.015	0.146
D(EI(−1))					0.134	0.921
D(PATENT)			1.553*	1.818		
D(FG)	0.042	0.760	0.062	1.097	0.061	0.786
D(FG(−1))					0.217***	3.920
D(FG(−2))					0.095	0.585
D(GS)	0.314**	2.007	0.171	0.745	1.616***	10.25
D(GS(−1))					0.947***	3.013
D(GS(−2))					0.597	1.537
D(HC)	0.684	0.432	0.873	0.579	0.961	0.429
D(HC(−1))					−0.925	0.394
C	4.184***	7.413	6.636***	7.751	7.957***	3.672
ECM(−1)	−0.780***	8.063	−0.746***	9.946	−0.664***	7.637

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 6
Economy-wise estimates of green growth.

Variable	Brazil Coefficient	t-Stat	Russia Coefficient	t-Stat	India Coefficient	t-Stat	China Coefficient	t-Stat	South Africa Coefficient	t-Stat
Short-run										
EI	0.581***	2.767	0.117	0.384	−0.205	0.746	0.635***	2.983	0.080	0.751
EI(−1)			0.791	2.815						
FG	0.127	1.231	0.034	0.589	0.034	0.306	0.176***	3.096	0.080**	2.290
FG(−1)							0.180**	2.156		
GS	0.720	1.427	0.601	1.402	1.069	1.642	0.764**	2.406	0.710	1.488
GS(−1)			1.031	1.076					0.620	1.014
HC	1.658	2.037	1.676	1.272	1.504	2.281	0.717	0.672	0.585	0.797
HC(−1)	1.723	1.366					1.925	1.351		
Long-run										
EI	0.471***	3.001	1.540***	4.471	0.147	0.723	0.761***	2.796	0.082	0.739
FG	0.103	1.212	0.026	0.609	0.025	0.303	0.146***	3.305	0.082**	2.506
GS	0.583	1.400	1.273***	4.280	0.767*	1.702	0.915***	2.789	0.428	1.154
HC	2.376	1.451	2.868	1.282	3.230**	2.112	2.162**	2.004	0.602	0.797
C	7.440*	1.888	6.474***	4.147	6.349	1.107	7.288***	4.870	5.847	1.249
Diagnostics										
F-test	7.235***		11.25***		4.635***		7.789***		5.986***	
ECM(−1)	−0.355***	7.394	−0.482***	9.547	−0.394***	5.947	−0.535***	7.777	−0.372***	6.635
LM	0.356		0.321		1.365		1.356		0.365	
RESET	0.524		1.254		0.147		0.365		1.542	
CUSUM	S		S		S		S		S	
CUSUM-sq	S		S		S		S		S	

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

also confirm the existence of long-run co-integration in basic and robust models.

Table 6 presents the economy-wise estimates for the green growth model. The ARDL method was used to obtain economic coefficient estimates. It has been reported that the impact of environmental innovation is significant and positive on green growth in Brazil, Russia, and China in the long run. The coefficient estimates show that a 1 percent increase in environmental innovation increases green growth by 0.471 percent in Brazil, 1.540 percent in Russia, and 0.761 percent in China in the long run. Financial globalisation brings about a significant and positive increase in green growth in the case of China and South Africa in the long run. This implies that a 1 percent increase in financial globalisation increases green growth by 0.146 percent in China, and 0.082 percent in South Africa, in the long run. Regarding control variables, the findings show that government spending increases green growth significantly and positively in Russia, India, and China in the long run. A 1 percent expansion in government spending improves green growth by 1.273 percent in Russia, 0.767 percent in India, and 0.915 percent in China in the long run. However, human capital tends to significantly increase green growth in India and China in the long run. It was found that a 1 percent rise in human capital tends to increase green growth by 3.230 percent in India and 2.162 percent in China in the long run.

The short-run findings reveal that environmental innovation causes a significant and positive improvement in green growth in the case of Brazil and China; however, the association is statistically insignificant for the remaining economies. Financial globalisation reports significant and positive improvements in green growth only in the case of China and South Africa. In terms of control variables, the findings show that government spending brings about a significant and positive increase in green growth only in the case of China, while human capital has a statistically insignificant impact on green growth in all BRICS economies in the short run. The results of some important diagnostic measures are shown in the lower panel of Table 6. The application of these tests was mandatory to confirm the validity of the results. The coefficient estimates of the F-stat and ECM terms confirm the long-run co-integration association among the variables in all models of the BRICS economies. Moreover, the negative sign associated with the coefficient estimates of the ECM term confirms the convergence towards stability. The results of the LM test confirm that no autocorrelation problem exists in the models. However, the Ramsey RESET and CUSUM tests confirm the correct specification and stability of the model.

Conclusion and implications

Over the last three decades, the issue of sustainability has received paramount importance, becoming the focal point of all international forums. As a result, the attention of policymakers, environmental experts, and researchers has shifted towards the notion of green growth, which necessitates the complete elimination of CO_2 emissions during the production process, leading to sustainable economic development. Although previous studies have primarily focused on the determinants of environmental quality, very few have focused on the aspects of green growth. To fill this gap in the literature, this study investigates the factors that can impact green growth in the BRICS economies. Following the latest estimation techniques, we checked the CD and panel unit root tests, which suggest that second-generation estimation techniques should be applied. Hence, we used the CS-ARDL model to solve the CD and slope heterogeneity issues.

The results of the CS-ARDL model confirm that the long-run estimates of environmental innovations and patents are positively significant, ensuring that environment-related technologies are helpful in attaining green growth in the BRICS economies. Likewise, the estimate of environmental invention is significant and positive in the ARDL-PMG model. Moreover, the estimates of financial globalisation are significantly positive in all three models, suggesting that financial globalisation expands green growth in the BRICS economies. While the estimates of GS are significantly positive in all models, those of human capital are significant only in the ARDL-PMG model.

Our findings have significant policy implications. The findings of the study imply that environment-related technologies help improve green growth; therefore, policymakers should focus on R&D activities that can promote the development of green innovations. For instance, policymakers should turn the flow of funds towards investment in green technologies, including renewable energy technologies, which will positively impact economic growth without compromising environmental quality. Meanwhile, it is also necessary to increase investment in R&D to develop technological innovation. Governments of BRICS nations should also implement measures to encourage industrial enterprises to adopt green innovation in the production process, removing any unnecessary barriers in the process.

Collaboration among major economies regarding the development of environmental technologies will be helpful in combating the menace of climate change and global warming. The rising level of financial globalisation has generated financial development in domestic markets. It is expected that well-developed and strong domestic financial markets can provide more funds for green innovation and the production and transfer of green technologies. Further, financial globalisation can also help economies collaborate financially to attain superior environmental practices and develop innovations that can help promote green growth.

The analysis has focused only on the BRICS economies; therefore, the inference drawn from the study should be used with great caution. Future studies should gather larger datasets and focus on other economies and regions. Another limitation of our study is that it provides a symmetric analysis of the concern variables. Future studies could explore the asymmetric impact of financial globalisation and green innovation on green growth. Future research could improve the definition of the green growth index by adding environmental services.

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