Public debt and GDP growth in BRICS: unravelling time-scale complexities through wavelet analysis

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Abstract

This study examines the impact of public debt on economic growth in BRIC nations – Brazil, Russia, India, and China – over 1996-2022 using wavelet coherence and cross-wavelet analysis to capture both short-term dynamics and long-term trends. The findings reveal a positive but heterogeneous co-movement between public debt and GDP, intensifying during COVID-19. Russia exhibits short-to-medium-term co-movement, while Brazil, India, and China show medium-to-long-term patterns. In Brazil and Russia, public debt drives growth during economic distress, whereas in India and China, growth leads to debt accumulation. Granger causality tests confirm the directionality of these relationships, supporting the robustness of the wavelet-based results. The study highlights the need for tailored debt management strategies aligned with country-specific economic conditions to support sustained and inclusive growth.

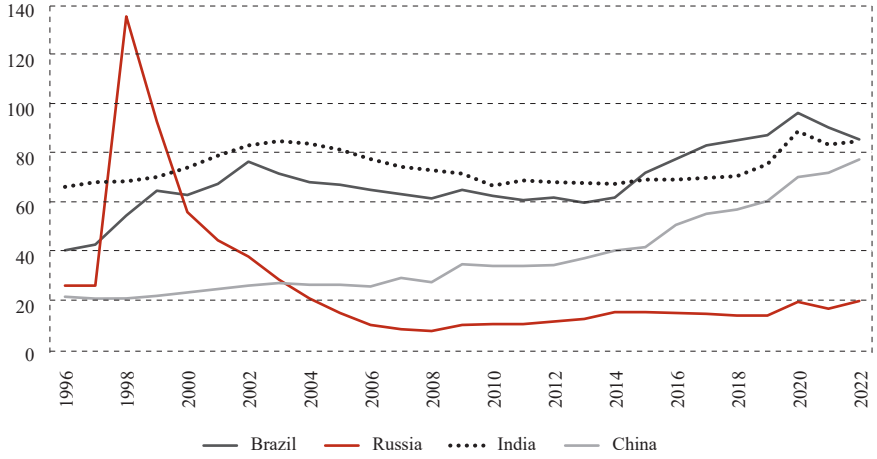
Keywords: public debt, economic growth, BRICS, wavelet analysis, emerging nations, COVID-19

1 INTRODUCTION

Countries across the world are grappling with astronomical levels of sovereign debt. Since the Global Financial Crisis in 2008, countries have been consistently trying to contain their debt ratios; however, the issue was exacerbated exponentially after the COVID-19 pandemic disrupted fiscal health globally. This time, the impact is seen as more severe in the emerging market economies. As many as 47 developing countries are expected to hit external debt indebtedness thresholds by or before 2029. These countries will have to shell out a whopping $400 billion to service external debt in FY 2024-25 alone (IMF, 2024). Within the emerging market economies, the central role of four major countries, i.e., the original members of the BRIC nations (Brazil, Russia, India, and China) is becoming magnified; their contribution to world economic output grew from 18% in 2010 to more than one-fourth in 2021, registering an astounding growth of 44% in just 12 years. In parallel with their economic output, these nations account for slightly more than 40 percent of the world population and 16 percent of global trade. Unlike advanced economies, which thrive on global demand, government spending is the central axis around which the domestic demand-driven growth in the emerging market economies revolves. However, rising debt servicing and repayment costs reduce the elbow room for capital-intensive fiscal policies in these countries. Figures 1 and 2 showcase the changes in public debt levels and GDP growth rates over the years in BRIC countries.

Figure 1

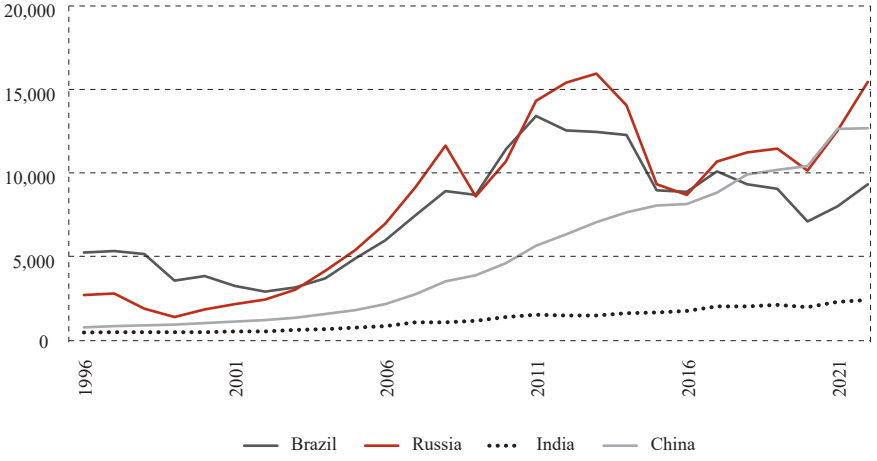
Public debt from 1996 to 2022 in BRIC countries (general government debt as a percentage of GDP)



Source: Authors' compilation.

Figure 2

GDP growth from 1996 to 2022 in BRIC countries (GDP per capita in USD; current price)



Source: Authors' compilation.

The existing studies on the connection between public debt and economic growth reveal a lack of consensus on several key aspects. Scholars present conflicting views regarding the threshold levels, their long-term and short-term effects, and the asymmetric nature of the relationship, leading to ongoing debates in the literature. Additionally, there is a notable absence of multi-scale analytical approaches, such as wavelet analysis, in examining this relationship. Moreover, recent studies have predominantly focused on the 2008 global financial crisis (Turan and Iyidogan, 2023;

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Kassouri et al., 2021; Butkus et al., 2021) as a pivotal event shaping the discourse. The significant increase in government spending due to the COVID-19 pandemic and the resultant surge in borrowing by governments worldwide has received insufficient attention. Furthermore, most empirical studies have concentrated on developed economic blocs (Abubakar and Mamman, 2021; Esteve and Tamarit, 2018; Baum, Checherita-Westphal and Rother, 2013), overlooking the unique challenges faced by emerging nations characterized by underdeveloped private investment, inadequate financial infrastructure, and consistent policy uncertainty. Consequently, the changing aspects of public debt and growth in these contexts warrant further investigation to provide a more contextual understanding of the issue.

Existing empirical literature on the debt-growth dynamics, although it has adopted extensive datasets and robust econometric methods, remains inconclusive. Reinhart and Rogoff's (2010) influential study, based on two centuries of data from 44 countries, suggested that gross domestic product tends to slow down after the debt-to-GDP ratio crosses the threshold of 90%. However, this threshold has been contested due to variations in data, countries, and methodologies, as highlighted by subsequent studies (Eberhardt and Presbitero, 2015; Panizza and Presbitero 2014; Herndon, Ash and Pollin, 2013; Baum, Checherita-Westphal and Rother, 2013). Notably, research indicates a much lower debt threshold for emerging economies (Asteriou, Pilbeam and Pratiwi, 2021; Law et al., 2021; Gunarsa, Makin and Rohde, 2019; Ndoricimpa 2017; Mencinger, Aristovnik and Verbic, 2015; Woo and Kumar, 2015).

Considering the economic importance of the BRIC countries and the potential global repercussions of mismanaged public debt within these nations, this paper will empirically analyse the influence of public debt on the economic growth of BRIC from 1996 to 2022, utilizing the wavelet method, thus covering both systemically significant events, i.e., the 2008 global financial crisis (GFC) and the 2019 coronavirus pandemic. The primary contribution of this paper lies in the application of a wavelet transformation method, which allows for a detailed analysis of public debt and economic growth dynamics across different time scales. This approach provides deeper insights regarding the causality between public debt and gross domestic product. The wavelet power spectrum characterizes the spectral density or energy of the time series. Annual data for the time-period is plotted on the horizontal axis from 1996 to 2022, and periods or scales are represented on the Y-axis for the wavelet transformation. Periods or scales are akin to camera lenses, which help expand or contract the wavelet power in varying intervals, i.e., short, medium, and long-term, thus providing simultaneous insights into both time and frequency domains.

The public debt-growth relationship is indeed a dynamic subject, and the literature available on its role in a nation's macroeconomic stability and progress is continuously evolving. The wavelet spectrum model adopted in this study is an extension of existing studies that investigate the nuances of this debt-growth nexus. The study also brings the spotlight on the emerging group of countries that are becoming systemically very important for driving future global economic growth. The

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unexplored novelty in terms of methodology and data sample will provide deeper insights into the critical linkages of public debt and gross domestic product. When it comes to emerging nations, this topic remains a scantily studied dimension in the literature, and yet it is pivotal for policymakers to consider these contextual realities while devising future borrowing programs.

The remaining paper is ordered as follows. Section 2 provides a brief theoretical background and a detailed review of the existing studies *vis-à-vis* the debt-growth nexus, highlighting the dominant threads in terms of sample, methodologies, and findings. In section 3, we explain the data and the research methodology adopted in the study. The empirical results and findings are presented in section 4. Finally, in the last section, we provide the conclusion of our manuscript while also embarking on the theoretical and policy implications.

2 LITERATURE REVIEW

Since the mid-18th century, the interaction of public debt and economic growth has been extensively debated both theoretically and empirically (Hume, 1752; Smith, 1776; Ricardo, 1820; Keynes, 1935; Hansen, 1938; Samuelson, 1938; Barro, 1974; Buchanan, 1976; Blanchard, 1985). Classical economists (Hume, 1752; Smith, 1776; Ricardo, 1820) argued that government borrowing, as a politically convenient but inefficient fiscal tool, leads to capital waste and burdens future generations, emphasizing long-term negative impacts. Conversely, the Keynesian school (Keynes, 1935; Hansen, 1938; Samuelson, 1938) posits that sovereign debt can stimulate economic output by increasing aggregate demand and boosting private investment. Neoclassical theorists introduced the Ricardian Equivalence Theory (Barro, 1974), suggesting debt neutrality, where rational agents anticipate future taxes to offset debt, thus leaving aggregate demand, growth, and interest rates unaffected. Contemporary empirical evidence is extending these theoretical frameworks in several directions.

The global financial crisis of 2008 rekindled the interest of the research community in the dynamics of public debt and its interaction with economic growth. Several studies with wider data sets and modern econometric methodologies were conducted to put established theories to the test. One such study was conducted by Carmen Reinhart and Kenneth Rogoff in 2010 using a dataset of 44 countries with around two centuries of observations. The study found that growth tends to be negatively affected once the debt-to-GDP ratio crosses 90%, and for emerging market economies, growth turns negative at only 60% in the case of the external debt portion. Further studies by Checherita-Westphal and Rother (2010) and Afonso and Jalles (2012) complemented the non-linear influence of debt on economic growth. These studies were followed by an intensified debate about the generalization of these threshold levels. A study by Herndon, Ash and Pollin (2013) questioned the conclusions of Reinhart and Rogoff on the grounds of choice of data, coding errors, and statistical relevance. The study established that after correcting for data and statistical inconsistencies, growth rates do not vary below or above the threshold of 90%. The threshold levels were, however, found to be significantly dependent

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on the choice of period and country. A number of other studies also contested the universality of the debt threshold level (Eberhardt and Presbitero, 2015; Egert, 2015; Panizza and Presbitero, 2014).

In addition to this, the empirical evidence also suggested that the threshold levels vary between advanced countries and emerging and developing nations (Mencinger, Aristovnik and Verbic, 2015). Using a dynamic threshold panel methodology, a study by Baum, Checherita-Westphal and Rother (2013) focused on twelve European area countries for the 1990-2010 period. The results suggested a significant positive short-term influence on GDP growth with 67% as a turning point for the public debt-to-GDP ratio, where the significance of the impact becomes zero. The study also found that above a threshold of 95%, there is an adverse impact of incremental debt on economic output. Using growth regressors, Cecchetti, Mohanty and Zampolli (2011) conducted a study on OECD countries during 1980-2010. Their results suggested that debt impacts economic growth negatively after hitting a threshold of 85% of the gross domestic product. Some studies focused on advanced economies (Abubakar and Mamman, 2021) extended the field of study into more detailed nuances like sovereign debt's transitory and permanent effect on economic growth. On the other hand, research with data sets from emerging and developing nations suggested much lower debt threshold levels. A recent work on emerging and developing market economies by Kassouri et al. (2021) adopted the interactive fixed effects (IFEs) approach and dynamic panel threshold methodology on panel data of 62 emerging and developing market countries for the 2000-2018 period. The results reveal an inverted U-shaped relationship between public debt and economic growth, which becomes statistically significant in the long run. In contrast, the short-run relationship lacks substantial statistical significance. Additionally, the study did a separate analysis for the low-income sub-sample, and it was found that the threshold level at which an increase in public debt harms economic output tends to be lowest among low-income countries across all income sub-groups. A study conducted by Law et al. (2021) focused on a panel of seventy-one developing countries from 1984 to 2015. In this study, the dynamic panel threshold technique was used to examine the threshold debt value. Diverging from previous studies, the results showed a lower threshold value of 51.65 percent.

3 DATA AND METHODOLOGY

3.1 DATA

The two variables under study, i.e., the gross domestic product as well as the gross government debt have been taken from the World Development Indicators database of the World Bank and the International Monetary Fund (IMF) respectively. The sample comprises four emerging nations of the BRIC block, i.e., Brazil, Russia, India, and China in the shape of panel data for the 1996-2022 period. The choice of the period was primarily driven by data availability. Table 1 explains the dependent and independent variables used in the study. Wavelet analysis was used to determine the relationship between levels of public debt (explanatory variable) and economic growth.

Table 1
Variables, definitions, and sources

Variables	Measurement	Source	Type
Gross domestic product	Annual percentage growth rate of GDP at market prices based on constant local currency	World Development Indicators – World Bank	Dependent
Gross government debt	General government debt, total (% of GDP)	International Monetary Fund	Independent

Source: Authors' compilation.

Economic growth, the dependent variable, is expressed in the annual percentage growth rate of gross domestic product (GDP), measured at market prices based on constant local currency. GDP aggregates are based on constant 2015 prices, expressed in U.S. dollars.

Public debt, the independent variable, is expressed in general government debt (GGD) as a percentage of GDP. GGD is the gross debt of the general government. Its components include currency and deposits; debt securities, loans; insurance, pensions and standardised guarantee schemes, and other accounts payable. As per the existing literature, GGD is a key indicator for measuring the sustainability of government finance as well as for assessing the changes in government debt over time. It primarily reflects the impact of past government deficits (Afonso and Alves, 2014).

3.2 METHODOLOGY

Public debt has been steadily increasing worldwide, particularly in emerging countries, following the 2008 global financial crisis and the recent COVID-19 pandemic. This study will attempt to analyse the growing public debt in the case of BRIC nations and its influence on economic growth by adopting the wavelet approach. Using a multi-scale analytical approach, we shall be looking through the lens of time as well as the frequency dimension.

By incorporating both time and frequency domains, wavelet analysis addresses the limitations of conventional time series analysis in studying economic dynamics. Three main properties of wavelet analysis that improve the comprehension of information hidden in economic data include: 1) Immunity to non-stationarity of data, 2) Resolution of data in different time scales, 3) localization of data in both time as well as frequency domains (Albu and Albu, 2021). To substantiate the consistency of the results we conducted a country-wise Granger causality analysis.

This study aims at uncovering the causal relations between Public Debt and Economic Growth for various time scales. Besides analysing causality for the original frequency, using wavelet analysis we will also investigate this relationship at different frequencies in the context of the time scales by decomposing the series appropriately. Table 2 shows the time scales corresponding to different frequencies that have been obtained using the wavelet transformation.

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Table 2
Time scale intervals

Time scale	Horizontal axis (in years)
1-5	1996-2000
6-10	2001-2004
11-15	2005-2008
16-20	2009-2012
20-25	2013-2016
26-30	2017-2022

Source: Authors' compilation.

The fact that most of the data in economic time series is a result of economic agents making decisions with varying time horizons, bifurcating time series data into different layers of frequency makes wavelet analysis the most appropriate tool. This is done by assuming the original time series as a function of time, which is then sliced into its low and high-frequency components by adopting wavelet scaling filters. Finally, the wavelet coefficients obtained at each frequency level are a representation of its corresponding time scale.

In this analysis, the wavelet model (ψ) is a modified form of the Morlet wavelet. The corresponding equation for this wavelet is shown in equation (1).

$$\Psi(t) = \pi^{\frac{1}{4}} e^{-i\omega 0t} e^{-t\frac{2}{2}} \tag{1}$$

Research by Rua and Nunes (2009) confirms that the Morlet wavelet is widely utilized in analysis. In this model, (ω) represents frequency, commonly set to 6 to achieve a balance between the time and frequency domains, while (t) represents the precise point at which the wavelet is applied to a time series with closely spaced observations. Wavelet coherence measures the localized correlation between two-time series over a range of frequencies and time scales (Torrence and Webster, 1999).

The wavelet coherence equation, as defined by Torrence and Webster (1999), is presented in equation 2.

$$R^2(u,s) = \frac{|\, s\left(s^{-1} w_{xy}(u,s)\right)|^2}{s\left(s^{-1}|\, w_x(u,s)|^2\right) s\left(s^{-1}\,|\, w_y(u,s)|^2\right)}, \tag{2}$$

In wavelet coherence analysis, the smoothing factor (s) is critical; without it, coherence would reach a value of 1 across all frequency and time dimensions. Coherence values range from 0 to 1, analogous to correlation coefficients, indicating the degree of co-movement. Values near 1 imply a strong correlation, while those close to 0 suggest a weak or no correlation (Kiviaho et al., 2012). Graphical representations employ colour coding to convey the strength of co-movement, with red signifying high correlation and green indicating no correlation. Significant regions are identified using dark colours within a cone of significance at the 5% level, while areas outside this cone are considered insignificant.

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The Cross-wavelet representation is given by equation 3:

$$W_{(xy)}(u,s) = W_x(u,s).W_y*(u,s) \quad (3)$$

where (Wx) and (Wy) are the transformed wavelets, (u) denotes location, and (s) represents scale. Arrows play an essential role in image analysis (Loh, 2013). When arrows point from right to left, the series move together and are in phase. Conversely, arrows pointing from left to right indicate opposite movement or anti-phase. An upward arrow shows that the first time series leads, while a downward arrow suggests that the second series leads.

4 RESULTS AND DISCUSSION

Using annual data, the study has taken a sample of four BRIC member states to analyse the relationship between GDP growth and public debt for 1996-2022 period. The data was extracted from World Bank and IMF databases. Table 3 provides a detailed overview of the descriptive statistics for the data collected from the four countries. The mean and median help to measure central tendency, indicating the typical value for each variable. The maximum and minimum values give a sense of the range within which the data points fall. The standard deviation quantifies the variability or spread of the data, showing how much individual data points deviate from the average. Skewness measures the asymmetry of the data distribution, while kurtosis assesses the peakedness of the distribution, providing additional insights into the shape of the data. We used RStudio as the software tool for the analysis. The WaveletComp package in R was employed to calculate the wavelet power spectrum for the selected variables, while wavelet coherency analysis was applied to assess the correlation between GDP growth and general government debt (Roesch and Schmidbauer, 2016). This approach enabled a detailed examination of both the strength and pattern of the relationship between these variables across different time and frequency scales. We also included Granger causality analysis to check the reliability of the wavelet results.

Table 3

Descriptive statistics

	Brazil		Russia		India		China	
	GGD	GDP	GGD	GDP	GGD	GDP	GGD	GDP
Minimum	40.23	-3.60	07.45	-7.80	20.60	02.24	66.00	-5.80
Maximum	96.01	07.53	135.20	10.00	77.10	14.20	88.50	09.05
Mean	68.49	02.20	26.03	02.77	37.64	08.47	74.00	06.16
Median	64.70	02.21	15.14	04.02	33.77	08.45	71.50	07.24
LCL mean	63.23	01.10	14.81	01.00	30.92	07.47	71.30	04.99
UCL mean	73.74	03.29	37.25	04.54	44.37	09.46	76.70	07.33
Variance	176.40	07.66	804.60	20.00	289.10	06.32	46.90	08.80
St. dev.	13.28	02.77	28.37	04.48	17.00	02.51	06.85	02.97
Skewness	00.07	-0.40	02.56	-0.55	00.97	-0.28	00.61	-2.40
Kurtosis	-0.30	-0.30	06.33	-0.55	-0.38	00.73	-1.13	07.09

Note: Number of observations = 27.
Source: Authors' computer estimation.

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4.1 WAVELET COHERENCE SPECTRUM: ECONOMIC GROWTH AND PUBLIC DEBT

The wavelet coherence spectrum characterizes the spectral density or energy of the time series. Annual data for the time-period is plotted on the horizontal axis from 1996 to 2022, and periods or scales are represented on the Y axis for the wavelet transformation. The scales exhibited in table 2 allow for the adjustment of wavelet power, either expanding or compressing it to capture variations across short-term, medium-term, and long-term intervals. Shorter time scales (near the bottom of the graphs – figures 3 to 6) capture short-term relationships, while longer time scales (near the top) capture long-term relationships. This flexibility enables a more granular analysis of patterns and fluctuations within different time horizons, enhancing the interpretive depth of the wavelet analysis. In the wavelet power spectrum, the intensity of the power is represented by colours. Blue signifies the periods with a lower wavelet power spectrum while red depicts a higher wavelet power spectrum. If there is a substantial variability in the wavelet power spectrum colour, it represents the inherent volatility of the series of variables.

In all four heat maps (figures 3-6) of the wavelet power spectrum of the BRIC countries, the white cone-shaped curve shows the cone of effect, showcasing the demarcation beneath which the discontinuity impacts the wavelength strength. The dark black contour represents a 5% significance level calculated by the Monte Carlo simulation.

4.1.1 Brazil

As indicated by the black contour regions, the wavelet coherence spectrum for Brazil depicted in figure 3 reveals strong coherence in specific periods, particularly around 2009-2012, 2013-2016, and 2017-2022. The coherence is more pronounced in the medium-to-long-term scales (above 10 years), suggesting that the relationship between Brazil's public debt and economic growth strengthens over longer horizons. The red and yellow zones signify high synchronization, while blue areas indicate weak or no correlation. The 2009-2012 coherence could be linked to the global financial crisis and Brazil's fiscal responses, the 2013-2016 period aligns with Brazil's economic recession and debt struggles, and debt policies, economic recovery, and COVID-19 may influence the 2019-2022 coherence.

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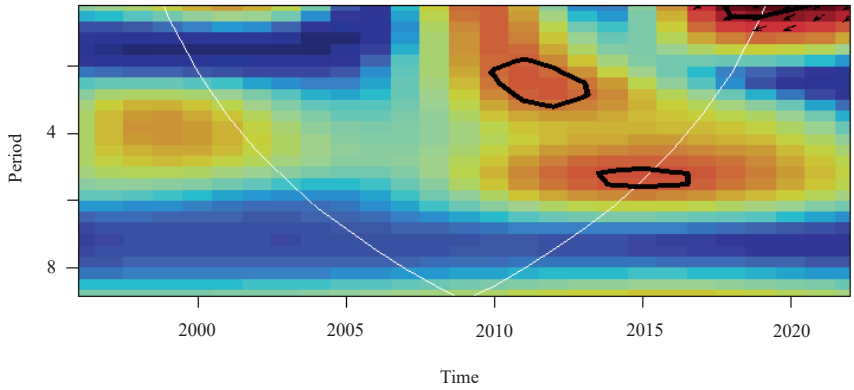
Figure 3
Brazil wavelet coherence spectrum

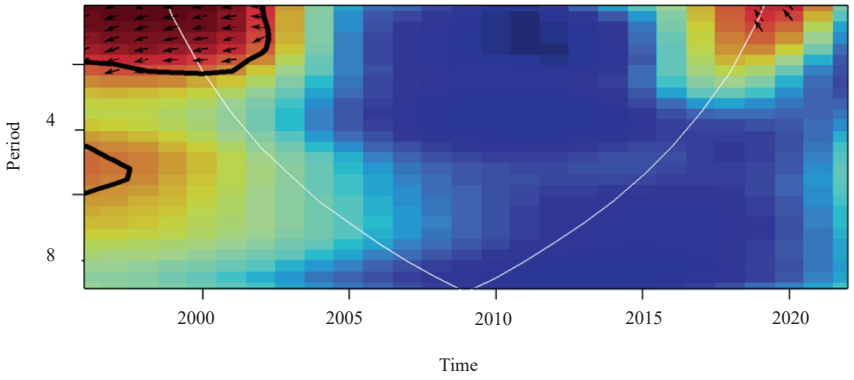


Source: Authors' computer estimation.

4.1.2 Russia

The wavelet coherence spectrum for Russia depicted in figure 4 reveals strong coherence primarily in the early years (1996-2000) and towards the end of the sample period (2017-2022), as indicated by the black contour regions. The coherence is concentrated in shorter time scales, suggesting that the relationship between public debt and economic growth in Russia is more significant in the short-to-medium term than in the long run. The red and yellow zones signify high synchronization, whereas the blue areas indicate weak or no correlation. The early period coherence might be linked to Russia's financial crisis of 1998 and its economic restructuring after the disintegration of the USSR, while the more recent coherence could be influenced by fiscal policies, COVID-19 shock, and geopolitical factors, including sanctions and oil price fluctuations. This suggests that the debt-growth relationship is stronger in Russia in crisis-driven periods.

Figure 4
Russia wavelet coherence spectrum



Source: Authors' computer estimation.

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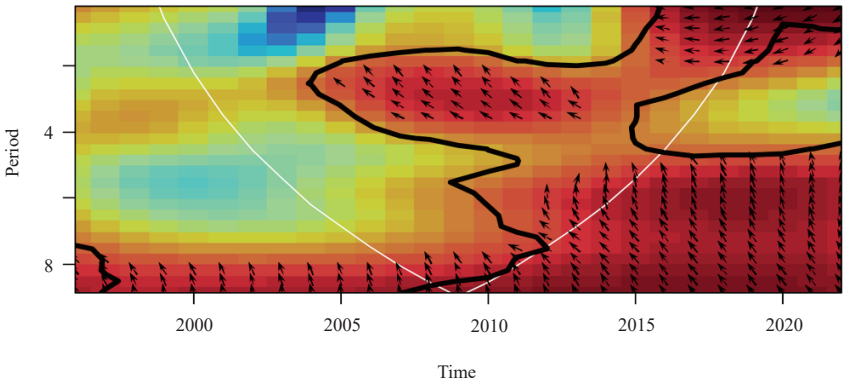
4.1.3 India

Unlike the other three countries of the BRIC block, the wavelet coherence spectrum of India depicted in figure 5 shows strong coherence across multiple periods, particularly from 2003-2008, 2010-2016, and 2018-2022, as indicated by the black contour regions. The widespread coherence across medium-to-long-term scales suggests a persistent and evolving relationship between public debt and economic growth in India. The dominance of red and yellow zones signifies high synchronization, whereas minimal blue regions indicate that the correlation remains relatively strong over time. The coherence observed during 2003-2008 may be linked to India's deepening global economic integration after the economic liberalization of the 1990's, 2010-2016 could be influenced by fiscal consolidation and global economic events after the GFC, while 2018-2022 likely reflects the impact of rising public debt, structural reforms, and the economic fallout of COVID-19.

Figure 5

India wavelet coherence spectrum



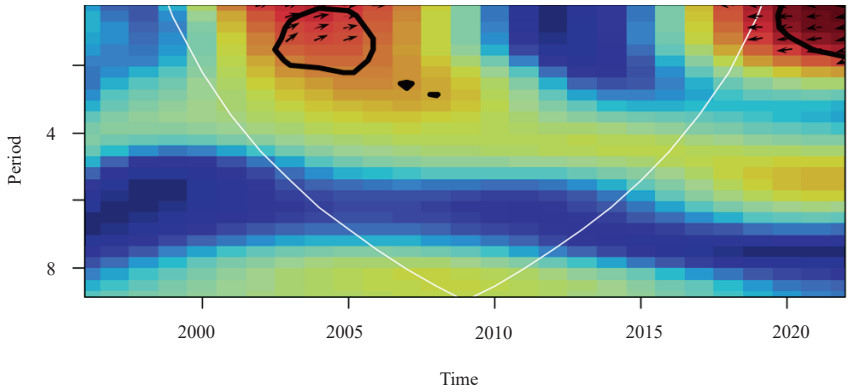
Source: Authors' computer estimation.

4.1.4 China

The wavelet coherence spectrum depicted in figure 6 highlights key periods where public debt and economic growth in China were closely linked, aligning with the country's economic conditions. The strong coherence around 2003-2007 coincides with China's rapid industrial expansion and WTO accession (2001), which fuelled economic growth and government spending on infrastructure. The weaker coherence from 2010-2018 aligns with China's shift towards a consumption-driven economy, tighter financial regulations, and efforts to curb excessive local government debt, reducing the immediate impact of public debt on growth. The renewed strong coherence in 2019-2022 reflects China's aggressive fiscal stimulus and rising debt levels in response to the COVID-19 pandemic, reinforcing the link between debt-financed stimulus and economic performance. The mid-term dominance (10-15 years) suggests that debt policies in China have long-term cyclical impacts, likely influenced by major policy shifts, global economic conditions, and internal structural changes.

Figure 6

China wavelet coherence spectrum



Source: Authors' computer estimation.

Across all four countries, the highest wavelet coherence values are observed during 2019-2022, coinciding with the global financial distress caused by the COVID-19 pandemic, reinforcing the heightened interaction between public debt and economic growth. However, each country also displays unique patterns beyond the pandemic period. In Brazil, strong coherence appears in the medium-to-long-term scales, particularly during 2009-2012, 2013-2016, and 2019-2022, linked to the global financial crisis, the country's economic recession and debt management strategies. Russia exhibited strong coherence in the early years (1996-2000) and again in 2017-2022, with a short-to-medium-term dominance, likely reflecting the economic restructuring post-USSR and the recent impact of fiscal policies, COVID-19, and geopolitical events. India's wavelet coherence spectrum, unlike the other BRIC nations, shows persistent and widespread coherence across multiple periods, particularly from 2003-2008, 2010-2016, and 2018-2022, suggesting an evolving and long-term relationship between public debt and economic growth, influenced by economic liberalization, fiscal consolidation, and post-COVID recovery measures. China's wavelet coherence spectrum on the other hand highlights three key periods: 2003-2007, marked by industrial expansion and WTO accession; 2010-2018, characterized by a shift towards a consumption-driven economy and financial tightening; and 2019-2022, when rising debt levels and aggressive fiscal stimulus in response to the COVID-19 pandemic reinforced the debt-growth nexus.

The wavelet coherence spectrum analysis demonstrates that both the COVID-19 pandemic and the past financial crises significantly influenced the public debt-economic growth relationship across the BRIC nations. While Brazil, India, and China show varying medium-to-long-term interactions, Russia exhibits a more persistent and short-to-medium-term coherence, suggesting structural differences in debt management and economic policy across these nations.

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Table 4

Summary: wavelet coherence spectrum for the BRIC nations

Country	Key periods of strong coherence	Dominant time scale	Underlying economic drivers
Brazil	2009-2012, 2013-2016, 2019-2022	Medium-to-long-term (>10 years)	Global financial crisis, economic recession, COVID-19 debt policies
Russia	1996-2000, 2017-2022	Short-to-medium-term	Post-USSR restructuring, financial crisis (1998), fiscal policies, economic sanctions, COVID-19 impact
India	2003-2008, 2010-2016, 2018-2022	Medium-to-long-term	Economic liberalization, fiscal consolidation, structural reforms, COVID-19 economic impact
China	2003-2007, 2019-2022	Mid-term dominance (10-15 years)	Industrial expansion, WTO accession, financial tightening, fiscal stimulus in response to COVID-19

Source: Authors' compilation.

4.2 CROSS-WAVELET COHERENCE ANALYSIS: PUBLIC DEBT AND ECONOMIC GROWTH

We employed cross-wavelet analysis to investigate the timing and directional relationship between changes in general government debt and gross domestic product within the BRIC nations. This approach enables us to observe how shifts in one variable may precede or follow shifts in the other, capturing their dynamic interaction across time and frequency domains. As a result, it provides a deeper understanding of the correlation strength over different time periods. Wavelet coherence for each pair is plotted in figures 7-10, which presents the interdependence and co-movement of the time series, defined by arrows. Given the fact that the calculations are done on annual data, we have plotted time on the horizontal axis while frequency is plotted on the vertical axis. The colour schemes represent co-movement. Stronger co-movement is signified in red while weaker co-movement is represented in blue. Besides this, a significance of 5% for wavelet coherence is represented by the black contour in the figures.

Moreover, the small arrows in the figure depict phase differences. For the two variables to be in complete synchronization, the direction of the arrows has to be toward the right. The left pointing arrows represent that the variables move in anti-phase.

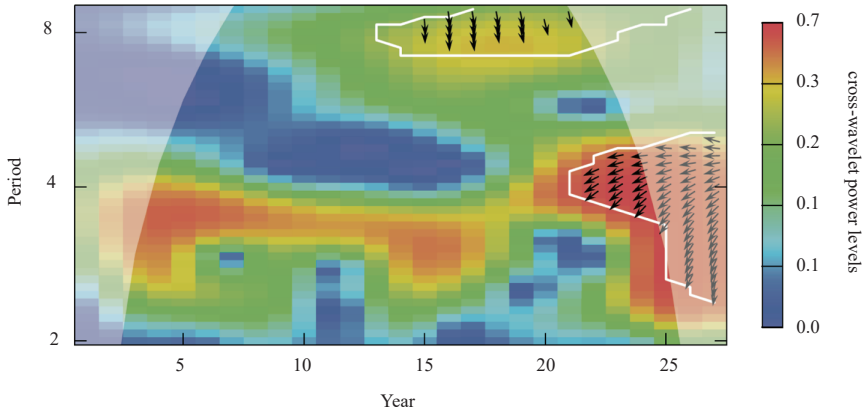
If the arrows point to the upper right or lower left, this indicates that the first variable is ahead of, or leading, the second. Conversely, if the arrows point to the lower right or upper left, it shows that the second variable is ahead, while the first is trailing.

4.2.1 Brazil

In figure 7, the cross-wavelet analysis for Brazil reveals a strong relationship between public debt and economic growth, particularly during 2009-2013 and 2017-2022, where increased fiscal intervention and crises led to greater coherence. The 2017-2022 period aligns with Brazil's rising debt, recessionary pressures, and COVID-19-related stimulus, with phase arrows suggesting that public debt changes led to economic growth. Similarly, 2009-2013 reflects Brazil's post-2008 financial crisis recovery, where stimulus measures strengthened the debt-growth link. Conversely, 1996-2009 shows weak coherence, indicating a less direct impact of debt on growth during early economic reforms and pre-global financial crisis stability. The results suggest that Brazil's public debt significantly influences economic growth during periods of crisis and intervention, particularly in medium-term cycles (4-8 years)

Figure 7

Brazil cross wavelet coherence



Source: Authors' computer estimation.

4.2.2 Russia

Figure 8 illustrates the cross-wavelet analysis for Russia. It shows a strong relationship between public debt and economic growth during 1996-2005 (Time Scale 1-10 years), with high coherence indicating a significant interaction influenced by Russia's post-Soviet economic transition, the 1998 financial crisis, and subsequent recovery. The phase arrows in this period predominantly point rightward and slightly upward, suggesting that public debt was leading economic growth, meaning that changes in debt levels influenced growth dynamics with a short lag. This reflects Russia's economic recovery heavy dependence on government intervention and debt management. After 2005, the coherence weakens, aligning with Russia's improved fiscal discipline, high oil revenues, and reduced reliance on public debt. From 2010-2022, the lack of strong coherence suggests that economic growth was more independent of debt, driven instead by resource exports and geopolitical strategies. Overall, public debt played a leading role in shaping economic growth during times of crisis and transition but became less relevant as Russia stabilized economically.

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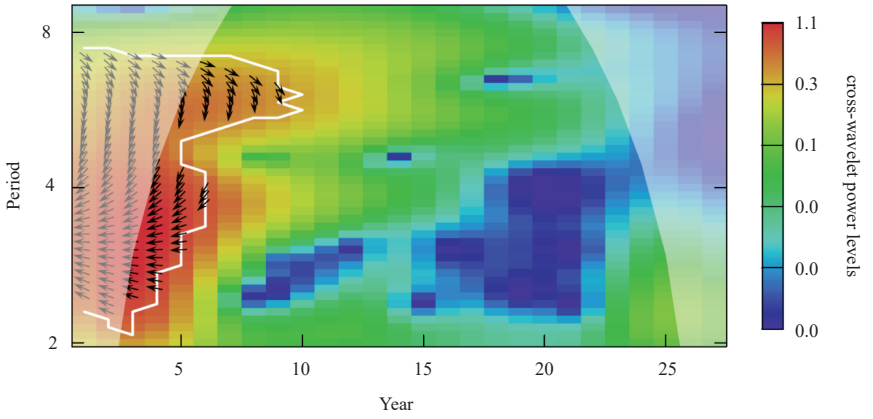
FIGURE 8

Russia cross wavelet coherence



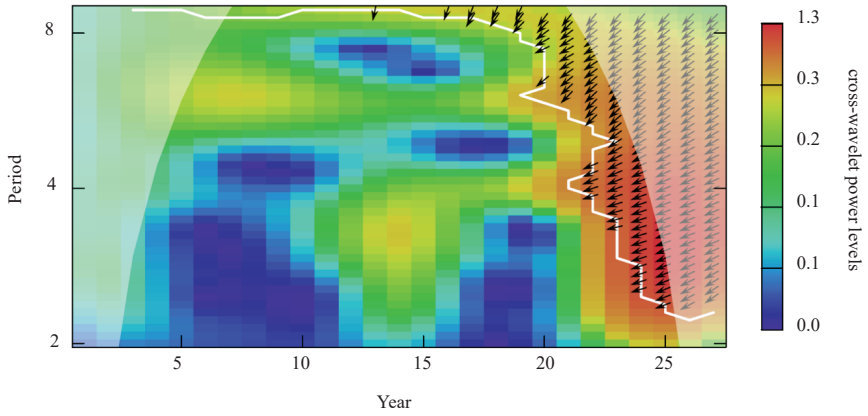
Source: Authors' computer estimation.

4.2.3 India

Figure 9 depicts the cross-wavelet analysis for India. It reveals a strong relationship between public debt and economic growth during 2015-2022, as indicated by the high coherence (red region) in this period. The phase arrows in this section predominantly point rightward and slightly downward, suggesting that economic growth is leading public debt, meaning growth fluctuations influenced debt accumulation, likely due to increased fiscal spending in response to economic expansions and contractions. This period aligns with India's major economic reforms, including the 2016 demonetization, the Goods and Services Tax (GST) rollout, and COVID-19-related stimulus measures, which significantly impacted both growth and public debt. Before 2015, coherence is relatively weaker, indicating a less direct relationship between debt and growth, potentially due to India's stable pre-2010 economic performance and cautious fiscal policies. The results suggest that in recent years, India's economic cycles have played a key role in shaping public debt trends rather than the other way around.

FIGURE 9

India cross wavelet coherence



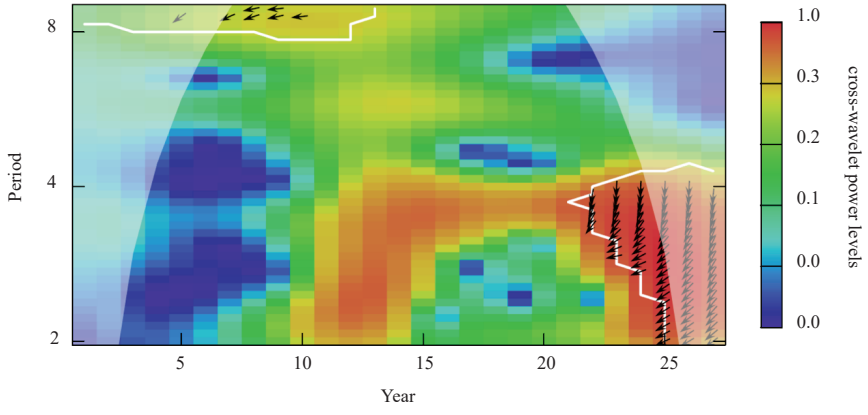
Source: Authors' computer estimation.

4.2.4 China

Figure 10 illustrates the cross-wavelet analysis for China. It indicates a strong relationship between public debt and economic growth during 2017-2022, where high coherence (red region) suggests a significant interaction between the two variables. The phase arrows in this period predominantly point rightward and slightly downward, indicating that economic growth is leading public-debt, meaning fluctuations in growth influenced the accumulation of debt. This aligns with China's COVID-19 stimulus measures, rising local government debt, and economic slowdowns due to pandemic restrictions and global trade uncertainties. Before 2017, coherence is weaker, suggesting a less direct link, particularly during China's high-growth period driven by infrastructure expansion and export-led strategies rather than debt-financed policies. The findings imply that in recent years, China's economic conditions have dictated debt accumulation rather than debt playing a dominant role in driving growth.

FIGURE 10

China cross wavelet coherence



Source: Authors' computer estimation.

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The cross-wavelet analysis exhibits heterogeneous patterns across the BRIC nations. For Brazil, significant coherence is observed during 2017-2022 and 2009-2013, periods associated with economic crises and fiscal interventions. The results suggest that public debt led economic growth during these times, emphasizing the role of fiscal policy in shaping macroeconomic stability. In Russia, the strongest correlation is witnessed during 1996-2005, a period marked by post-Soviet economic transitions and financial crises, where debt played a pivotal role in driving economic recovery. However, after 2010, the coherence diminishes as economic growth becomes more independent of public debt. In India, a significant relationship is found between 2015 and 2022, with arrows indicating that economic growth led public debt, suggesting that fluctuations in GDP influenced debt accumulation, especially during major policy reforms and COVID-19-related fiscal responses. Similarly, in China, strong coherence is evident during 2017-2022, where economic growth appears to lead public debt, reflecting the impact of pandemic-related stimulus measures and evolving fiscal policies.

The findings reveal that the debt-growth relationship varies across time and regions, with public debt playing a leading role during periods of economic distress in Brazil and Russia, whereas economic growth appears to drive public debt accumulation in India and China.

Table 5

Summary: cross-wavelet coherence analysis

Country	Periods of strong coherence	Leading variable	Economic context
Brazil	2009-2013, 2017-2022	Public debt	Economic crises, fiscal stimulus, post-2008 recovery
Russia	1996-2005	Public debt	Post-Soviet transition, financial crisis, fiscal interventions
India	2015-2022	Economic growth	Economic reforms (GST, demonetization), COVID-19 fiscal response
China	2017-2022	Economic growth	COVID-19 stimulus, rising local government debt

Source: Authors' estimation.

4.3 GRANGER CAUSALITY ANALYSIS

To check the consistency of wavelet analysis, we employed country-wise Granger causality tests (Granger, 1969). The test results provide further insights into the reliability of the lead-lag relationship between public debt (GGD) and economic growth (GDP), serving as a robustness check for the wavelet coherence findings.

Table 6
Granger causality test results

Country	F-statistic	P-value	Direction
Brazil	0.8332	0.4485	GDP → GGD
Brazil	0.8364	0.4472	GGD → GDP
Russia	1.7530	0.1977	GDP → GGD
Russia	4.7221	0.0203**	GGD → GDP
India	0.0243	0.0457**	GDP → GGD
India	3.5863	0.9760	GGD → GDP
China	3.4764	0.0051***	GDP → GGD
China	6.8495	0.0496**	GGD → GDP

Source: Authors' computer estimation.

In Brazil, the bidirectional causality between GDP and GGD is statistically insignificant, with high p-values (0.4485 and 0.4472), suggesting that neither variable strongly predicts the other. The wavelet coherence analysis, however, showed medium-to-long-term interactions with negligible immediate causal links. In Russia, the results indicate that GGD significantly influences GDP ($p = 0.0202$). However, the reverse causality is statistically insignificant ($p = 0.1977$). The results are consistent with the cross-wavelet analysis, which indicated public debt represented by GGD leading economic growth (GDP).

India exhibits unidirectional causality from GDP to GGD ($p = 0.0457$), while the reverse relationship is insignificant ($p = 0.9760$), indicating that economic growth plays a dominant role in shaping public debt rather than the other way around. This is in line with the cross-wavelet analysis where economic growth was leading public debt in the case of India, suggesting a structural relationship influenced by fiscal policies and economic reforms. For China, a bidirectional relationship is observed, with GGD causing GDP at a 5% significance level ($p = 0.0496$) and GDP influencing GGD more strongly ($p = 0.0051$). The latter also substantiates the cross-wavelet results where GDP was leading GGD in the case of China. This reinforces the wavelet findings that indicate strong coherence during industrial expansion, financial tightening, and fiscal stimulus periods. Overall, the Granger causality test reinforces the wavelet coherence and cross-wavelet findings by confirming the directionality of the debt-growth relationship across the BRIC nations, demonstrating structural linkages.

5 CONCLUSION

In its 2024 Global Economic Prospects report, the World Bank stressed that the global economy had experienced its slowest five-year growth period in 30 years spanning 2020 to 2024, even in the absence of a recession (World Bank, 2024). At just 3.3 percent in 2023, the global GDP is forecast to decelerate to only 3.1 percent by 2029. Compared to dismal growth numbers oscillating between 1.7 to 1.8 percent in advanced countries, the burden of growth is expected to be borne primarily by emerging nations. Emerging countries led by the BRIC block are

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expected to register economic growth between 4.2 to 3.9 percent by 2029 (IMF, 2024). Therefore, the role of emerging countries, particularly the BRIC bloc, in driving global economic growth is crucial for maintaining worldwide economic stability.

The rising public debt in emerging countries, on the other hand, is posing a serious challenge in realizing even these humble growth projections. Moreover, rising geopolitical tensions, such as the Russia-Ukraine conflict and Israel-Palestine disputes, are fracturing global trade into blocs. The borrowing program of emerging countries and their policy of using debt as a tool can decide the fate of global growth and its impact on socio-economic variables like employment and income levels (Ayoub, Wani and Sultan, 2024).

Against the backdrop of these unfolding realities, we studied the impact of public debt on economic growth of selected emerging countries from the BRIC block. Taking annual data for Brazil, Russia, India and China for the 1996-2022 period, we used wavelet analysis to analyse the relationship between gross government debt and gross domestic product. Wavelets have the capability to break down time series data into various time scales, enabling the detection of the way in which sovereign debt interacts with economic growth. Such influences may not be apparent when analysing data solely at its observed sampling rate, as the sampling blends multiple frequencies and conceals distinctions between short-term and long-term relationships (González-Concepción, Gil-Fariña and Pestano-Gabino, 2018; Aslan, Apergis and Yildirim, 2014). This distinction is crucial in studying the aforementioned relationship, as different factors may affect the connection between levels of public debt and economic output over short-term periods compared to long-term ones. We have used the wavelet coherence spectrum and cross wavelet coherence for our analysis. To further reinforce the findings, we used Granger causality tests for robustness.

The findings of our study indicate that (1) public debt and economic growth showed positive co-movement during the analysed period from 1996 to 2022 for all the four BRIC nations and economic growth in BRIC nations was notably vulnerable during the COVID-19 pandemic and the 2008 global financial crisis, with specific events such as the disintegration of the USSR affecting Russia during the early phase of the period under study. (2) For Russia, the co-movement was seen as strong in the short and medium term while as in case of Brazil, India, China the co-movement between public debt and economic growth was more pronounced in the medium-to-long run. (3) Across all four nations, public debt plays a crucial role in shaping economic growth dynamics, particularly during economic downturns. In Brazil and Russia, public debt serves as the primary driver of economic growth, especially in times of financial distress. Conversely, in India and China, economic growth appears to influence the accumulation of public debt, suggesting a growth-led debt expansion.

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5.1 THEORETICAL AND EMPIRICAL IMPLICATIONS

The results contribute to the existing literature in several ways. Firstly, wavelet coherence analysis reveals notable differences in the debt-growth relationship among the BRIC countries, reflecting each country's unique economic context. The link between debt and growth is shown as heterogeneous, with country-specific factors influencing the interaction, and no uniform threshold or frequency emerged at which public debt consistently triggered an effect on economic growth. These findings align with the empirical studies of Eberhardt and Presbitero (2015), Egert (2015), Panizza and Presbitero (2014), and Herndon, Ash and Pollin (2013). Secondly, our findings suggest that the debt-to-GDP ratio at which public debt most significantly impacts economic growth varies across time and frequency domains and varies among BRIC countries. This complements the empirical studies of Albu and Albu (2021), which focused on Eurozone countries with different economic structures and fiscal realities. By extending the analysis to emerging economies like the BRIC bloc, our results provide a broader understanding of the co-movements and causal directions of the debt-growth relationship. These results provide valuable insights enabling policymakers to have a better grasp of how public debt impacts economic growth in emerging markets.

5.2 POLICY IMPLICATIONS

The research findings exemplify the multi-faceted nature of the relationship between public debt and economic growth within emerging economies, particularly the BRIC countries. The increase in public debt during the COVID-19 pandemic has further normalized the already alarming trends of debt-to-GDP ratios in these countries. This development is alarming for policymakers. While public borrowing has played a critical role in mitigating the economic impact of the pandemic and supporting growth, the findings emphasize the importance of carefully managing debt policies to avoid negative long-term effects on economic stability.

Policymakers should be acutely aware of the directional causality between public debt and economic growth, as identified in this study, and the significant country-specific factors that influence this relationship. The results suggest that while debt can facilitate short-term economic expansion, unchecked borrowing may produce diminishing returns over time. Therefore, it is crucial to adopt debt policies that not only promote growth but also ensure debt sustainability by prioritizing fiscal responsibility and debt management strategies.

Given the higher debt levels observed in the wake of the pandemic and the ongoing geo-political upheavals, these findings should prompt prudent borrowing. Policymakers must focus on maintaining a healthy fiscal balance to avoid excessive reliance on debt that could stifle future growth. In particular, the findings stress the need for targeted borrowing strategies that align with the economic realities of emerging countries that underpin global growth prospects in the near future. By instituting policies that promote efficient debt usage, fiscal discipline, and sustainable development, emerging economies can safeguard both their long-term economic growth and their fiscal stability.

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6 SCOPE FOR FUTURE WORK AND LIMITATIONS

Challenges related to data availability restricted the selection of countries for this study. As a result, key emerging members of the BRIC group, such as South Africa, were excluded. Improved data access in terms of the number of countries, could significantly expand the scope of future research.

In addition to expanding the geographic scope, future research could benefit from the use of longer time series data. By incorporating data spanning several decades, researchers can better account for long-term structural changes in the global economy, the effects of historical crises, and the evolving role of public debt over time. This would provide deeper insights into the cyclical nature of debt and its impact on growth, particularly in the context of shifting global economic dynamics.

Disclosure statement

The authors have no conflict of interest to declare.

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