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Examining the Dynamics of Sensex and BRICS Stock Market: A Study on Interdependencies using VAR Framework

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Abstract

Aim: This study examines the long-run equilibrium relationship between the S&P BSE Sensex and BRICS stock markets using the Vector Autoregressive (VAR) framework. It also examines short-run relationships through causality models.

Methodology: To achieve the stated objectives, the researchers collected data from the Bloomberg database spanning January 2000 to September 2024. The collected data was tested for the existence of a unit root by running an ADF test, confirming the data's order of integration as I(1). Accordingly, the Vector Auto Regression framework was employed to examine the long-run relationship. Furthermore, to investigate the short-run relationship, Granger causality, IRF, and variance decomposition analysis were conducted.

Findings: Although the Johansen co-integration test results reveal a co-integrating vector, the error correction model reveals that Sensex does not share any long-run co-integration with BRICS stock markets and Sensex is largely driven by internal factors. However, short-run results indicate only MOEX and SSE significantly influence Sensex, while Variance Decomposition results demonstrate over ninety-five per cent variance of Sensex is driven by its internal factors, emphasising its limited dependence on BRICS stock markets.

Policy Implications: The results indicate that the policymakers should prioritise strengthening the stability of the domestic market to enhance resilience against global shocks. Moreover, fostering targeted collaboration with BRICS nations, specifically those with notable short-term influences such as MOEX and SSC, could assist in managing interdependencies very effectively.

Originality and Value: The current study offers original perspectives on the interlinkage between Sensex and BRICS stock markets, contributing to a deeper understanding of their dynamic long-run and short-run relationships. Furthermore, by applying advanced econometric tools like VAR, Granger causality, and IRF, it contributes to the existing literature on interconnectedness of BRICS stock markets and emphasises the relative independence of the Sensex.

Keywords: BRICS, Emerging Markets, Granger Causality, MOEX, Stock Market Integration, VAR Framework

JEL Classification Code: G10, G15, C32, F36

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Introduction

BRICS is an acronym for Brazil, Russia, India, China, and South Africa, formed from the first letters of these five powerful emerging economies of the world. BRICS epitomise an important force in the global economy, accounting for approximately 25 per cent of global GDP and 40 per cent of the global population, dazzling economic potential and demographic to cater to and bank upon (O'Neill, 2001; Wilson & Purushothaman, 2003). A study by Wilson & Purushothaman (2003) revealed that if the current path holds, the BRICS economy could become a significant player in the global economy. For instance, India's economy might overtake Japan's by 2032, while China's might exceed that of the US by 2041. Now, BRICS emerging as an important counterforce to the Western-dominated global financial market structures, aggressively working to reform global economic governance, including the creation of the New Development Bank (NDB), intended to fund infra-structure projects in developing nations (Cooper, 2016; Luna, 2020; Han & Papa, 2022). It also created the Contingent Reserve Agreement (CRA) to address the balance of payment crisis. In addition, the BRICS have even more aligned their policies on a wide range of burning issues such as education, agriculture, healthcare, and security (Han & Papa, 2022). Given their diverse economic fundamentals such as China's leadership in manufacturing, Russia's dominance defence exports, India's leadership in IT and IT enabled infrastructure to Brazil's agricultural exports the BRICS are strategically placed to complement each other, generating opportunities for greater trade and investment (Sharma, 2016; Stuenkel, 2020). However, the BRICS bloc faces major challenges, such as economic inequalities, geopolitical tensions, and sustainability issues, which emphasise the grave need for enhanced collaboration and strategic policy alignment within the trade bloc (Armijo 2007; Hopewell, 2015; Scholvin & Wigell, 2018). Addressing these challenges necessitates a unified framework that prioritises both economic and environmental objectives, nurturing resilience and inclusivity in a speedily changing scenario (Mielniczuk, 2013). As globalisation progresses, the BRICS trade bloc plays a vital role in driving economic growth and increasing the voices of developing and underdeveloped economies in the global arenas (Mielniczuk, 2013; Armijo & Roberts, 2014; Xing, 2019; Özekin & Sune, 2023; Rodriguez-Triocci, 2024).

Stock market integration denotes the process by which stock markets across the globe become more unified and interconnected, with security prices moving in response to shared global issues rather than being driven merely by local or regional specific factors. Many researchers concluded that the main driving force behind stock market integration is the advancement in information technology. These developments have not just driven stock markets towards risk diversification but also enhanced asset allocation

strategies and encouraged increased investment alternatives (Bekaert *et al.*, 2005, 2013; Arouri *et al.*, 2011). In addition, factors such as increased capital flow in the form of foreign direct investment and FIIs, liberalisation of financial markets (Saunders & Walter, 2002), which allow investors to diversify their portfolio across borders (Bekaert *et al.*, 2023). Additionally, examining stock market interlinkages among BRICS not only offers valuable insights into the economic synchronisation and likely to shed light on how major global financial events, such as policy announcements or shifts, economic crisis, affect the volatility and stability of the emerging markets (Singh *et al.*, 2022; Kaur *et al.*, 2023). As the BRICS economies deepen their financial collaboration, it is vital to investigate the extent of their stock market interconnectedness, predominantly in the context of cross-border trade, strategies for financial integration, and investment flow. In addition, BRICS markets have become very crucial economies due to their speedy growth, colossal population, and rise in contribution to global GDP, investment, etc., stressing the significance of studying their integration to understand the global stock market dynamics (Wilson & Purushothaman, 2003; Aizenman *et al.*, 2013). The integration of stock markets intensifies contagion risk, especially during financial crises, among BRICS economies, offering a valuable insight for understanding volatility transmission and market responses to such shocks (Bekaert & Harvey, 2000). Furthermore, understanding stock market integration within BRICS informs policy decisions intended at promoting economic resilience, such as mutual trade agreements, currency swaps, and promoting big financial institutions such as the BRICS Bank (NDB). These policy implications are likely to reduce dependency on highly organised Western financial systems and enhance regional cooperation (Chakrabarti & Sen, 2012; Gallagher, 2016; Stunkel, 2017). The dynamic linkage among BRICS markets offers stock market participants to diversify their portfolio and mitigate risk. Analysing BSE Sensex's relationship with other BRICS stock markets assists in understanding co-movement patterns and refining investment tactics (Mishra, 2012; Bekaert & Harvey, 2017; Maiti *et al.*, 2022; Sahoo & Kumar, 2022; Younis *et al.*, 2023). Moreover, advancements in information technology and its applications in the stock market, such as high-frequency trading and digital platforms, have augmented stock market interdependence, making it very essential to analyse these evolving dynamics (Arner *et al.*, 2015). Despite significant literature available on interlinkages of developed with emerging stock markets, research studies on BRICS stock market integration remain relatively unexplored. The majority of the studies aimed at individual market behaviours or spillover effects, overlooking interconnectedness and their implications for stock market stability (Bekaert & Harvey, 2017; Choudhary, 2018).

Finally, the reminder of the paper is organised as follows: part two discusses the literature review and raises the research questions, part three briefs out the research methodology employed for the study, part four aims on analysis of the collected data, and finally part five discusses the major findings with policy implications and draws conclusions.

Literature Review

A major chunk of the literature available on the stock market integration mainly focuses on the interlinkage of developed stock markets (Koch

& Koch, 1991; Masih & Masih, 1997; Francis & Leachman, 1998; Bracker *et al.*, 1999; Horvath & Petrovski, 2013; Lehkonen, 2015; Ma *et al.*, 2019; Marfatia, 2020) or interconnectedness of emerging markets with that of developed stock markets (Yang *et al.*, 2003; Mukherjee & Mishra, 2007; Awokuse *et al.*, 2009; Liu, 2013; He *et al.*, 2014; Al Nasser & Hajilee 2016; Zhang *et al.*, 2017; Patel, 2019). However, there is a relatively scarce number of empirical studies explicitly addressing the stock market interconnectedness within developing stock markets themselves, mainly among the BRICS nations. While previous studies primarily aimed at the integration of developed stock markets or emerging markets with developed stock markets, more recent literature has shifted attention to the dynamic interconnectedness within the BRICS market itself. Therefore, the stock market integration or interlinkage of BRICS markets has become a central point of empirical studies as these evolving economies seek to augment economic interlinkage and global competitiveness (Sharma *et al.*, 2011; Dasgupta, 2014; Singh & Singh, 2016; Ouattara 2017; Aggarwal & Raja, 2019; Gopane 2023; Singh *et al.*, 2022). The integration among BRICS markets not only fosters superior economic cooperation but is also likely to increase market efficiency and much-needed stability by providing diversified investment opportunities (Bekaert & Harvey, 2000). Studying developing stock markets, specifically the BRICS bloc, has gained momentum due to their increasing share in trade, investment flows, and share in global GDP (Wilson & Purushothaman, 2003). Furthermore, these economies, accounting for a significant share of global economic output and population play a very vital role in understanding dynamic market linkages, which are crucial for assessing financial stability, growth potential, and diversification of portfolios (O'Neill, 2001; Bekaert & Harvey, 2017; Choudhary *et al.*, 2020). Additionally, the interconnectedness of BRICS nations in the global financial system has deepened, making it a vital link to analyse their stock market interdependencies to better understand the transmission of global market shock waves, volatility spillover, and cross-border capital mobility (Bekaert & Harvey, 2000; Choudhary *et al.*, 2020). According to Stuenkel (2017), the BRICS economies' remarkable economic growth, demographics, and rising capital and financial markets have made them significant players in determining the future of cross-border trade and finance. The BRICS economies have arisen as key players in the global economy, with major contributions to global trade, GDP, and capital mobility (Wilson & Purushothaman, 2003). The BRICS nations have experienced extraordinary growth over the past few decades, mainly due to reforms, rapid industrialisation, and increasing consumer markets. In addition, BRICS nations jointly represent a large portion of the world's population and economic output, making their financial systems important to the international financial ecosystem (Aizenman *et al.*, 2013; Aizenman, 2015). The stock markets in BRICS nations, mainly those in China and India, have become important centres for global investment flows. According to Bekaert & Harvey (2000) and Stuenkel (2017), the increasing stock market interconnectedness of these emerging markets in the global arena has significantly increased their influence in global trade and investment, providing both opportunities and challenges for policymakers and investors.

The study of global stock market interlinkage has evolved from concentrating on developed stock markets to probing developing stock

markets like BRICS, mainly influenced by their swift growth, favourable economic policies, trade linkages, capital inflows, *etc*. (Arouri *et al.*, 2011). This paradigm shift emphasises the importance of understanding their changing role in global stability in financial markets. The financial crisis, such as the 1997 crisis of Asia and the 2005 sub-prime crisis, has further emphasised the importance of understanding stock market interconnectedness. These financial crises emphasised how shock waves creating in one part of the globe could cascade through interlinked global financial markets, affecting developed and developing markets alike (Bekaert & Harvey, 2000; Ng, 2000; Chancharoenchai & Dibooglu, 2006; Hwang *et al.*, 2011; Chiang *et al.*, 2013; Wang & Liu, 2016; Kao *et al.*, 2019). However, a few studies, for example, Xu & Hamori, 2012, Nikkinen *et al.*, 2013, Bergmann *et al.*, 2015, Mensi *et al.*, 2016, Kishor & Singh, 2017, Arora & Kalsie, 2018, have investigated how the BRICS nations' stock markets reacted to the global shock waves, emphasising the increasing co-movements of their markets with global market trends. In addition, the rapid stock market integration among BRICS nations has been shown to have important implications for risk management and financial market efficiency, emphasising the importance of this domain for more pronounced research (Ng, 2000). Recent empirical investigations emphasise the impact of macroeconomic variables, policy announcements (Dakhlaoui & Aloui, 2016; Mbangata & Kanayo, 2017; Yuan *et al.*, 2022; Gupta *et al.*, 2023), and geopolitical issues (Balcilar *et al.*, 2018; Zhang & Hamori, 2022; Feng *et al.*, 2023; Li *et al.*, 2024) on BRICS stock market integration, stressing both opportunities for collaboration and major challenges arising from structural differences. Most of these studies concluded that the growing attention on developing markets emphasises the major role of BRICS nations in reforming global market dynamics and shaping global financial integration (O'Neill, 2001). In a study by Wang and Wang (2024) investigated the interlinkage between BRICS economies, interest rate, investors sentiments, and cryptocurrencies, found a very strong information spillover during crisis period such as COVID-19. To explore the relationship, they employed a time-varying vector autoregression. They found a strong interconnectedness during highly uncertain periods like COVID-19, with minimal or virtually no impact on the US stock market. Several studies, for example, Bagchi (2017), Aggarwal and Raja (2019), Panda and Thiripalraju (2018), Qamruzzaman *et al.* (2021), Panda *et al.* (2021), Khan (2023), employed econometric tools such as ARCH, GARCH, DCC-MGARCH modelling framework to investigate the information spillover and its impact on BRICS markets. The findings from these studies confirmed that there was information spillover among the BRICS economies. These results emphasise the significant cross-market dependency, stressing the volatility policy framework to manage within the BRICS economies. Despite increasing stock market integration, major challenges continue. Differences in financial infrastructure, non-unified policy framework, extensive regulations, and external economic pressures continue to limit the accomplishment of BRICS stock market integration. Numerous studies have tried to investigate the integration of the BRICS stock market under Vector Autoregressive and Bayesian VAR models, yielding mixed results regarding the interlinkage among these economies. On one hand, Chittedi (2010), Sharma *et al.* (2013), Çakır and Kabundi (2013),

Dasgupta (2014), Singh and Singh (2016), and Singh *et al.* (2022) found an interconnectedness among the BRICS stock indices. These results confirm that shocks in one stock market are likely to affect others, supporting the proposed hypothesis of deeper interconnectedness within the BRICS bloc. However, other studies, such as Ouattara (2017), Konradsson & Porss (2019), and Malik and Sah (2023) using VAR models have contradicted the notion of stock market integration. They found only short-run evidence, and in the long run, they found significant structural differences.

Stuenkel (2017) emphasises the collective effort of BRICS economies on minimising excessive reliance on the U.S. dollar, and creating alternative platforms can create opportunities for deeper cooperation. Therefore, the connectedness of BRICS stock markets exhibits a very dynamic relationship of economic policies, geoeconomic interaction, and other global risk factors. While significant progress has been made, economic disparities and global uncertainties continue to guide the path of BRICS stock market integration.

Based on the above literature on BRICS stock market linkage, considering the VAR framework with a focus on both long and short-run relationships between BSE Sensex and BRICS economies, the following research questions have been raised to be addressed in the current study:

1. How do various global economic developments and policy shifts in BRICS nations influence the long-run equilibrium equation between the BSE Sensex and BRICS stock indices?
2. What role do regulatory structure and domestic policy framework in BRICS nations play in shaping short-run interconnectedness with the BSE Sensex?

The above two valid research questions cover both global economic events and policy regulations at regional levels that bind the financial integration of the Sensex with BRICS stock indices. Therefore, a deeper understanding of this interconnectedness is strategically very vital for policymakers, investors, and various major financial institutions (Wilson & Purushothaman, 2003; Stuenkel, 2017).

Research Design

The main scope of the current empirical study is to investigate the long-term relationship of Sensex with the BRICS stock market under VAR framework using indices such as Sensex (India) and SSE Index (China), MOEX (Russia), JSE-40 (South Africa), and Bovespa (Brazil) to capture the integration. Furthermore, to capture the short-run causal relationship of Sensex with BRICS stock indices by running short-run causality models. In addition to evaluating the policy implications of financial integration among the BRICS stock markets. To realise the stated objectives, the researcher collected data spanning from January 2000 to September 2024 from Bloomberg's financial database. To investigate the existence of unit root in the collected time series data, the Augmented Dicky-Fuller (ADF) test was run (Dickey & Fuller, 1979; Said & Dickey, 1984), which is widely used method to determine whether a time series is stationary or not (Kwiatkowski *et al.*, 1992). The general form of the ADF equation was as follows:

$$\Delta y_t = \alpha + \beta t + Y y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-1} + \varepsilon_t$$

where, y_t is the time series dataset under investigation, $\Delta y_{t=} y_t - y_{t-1}$ is the first difference of the series (to convert the data set into stationary), α is the constant term, βt is a deterministic trend component, γ is the coefficient of the lagged DV, $y_{t-1,}$ which tests for the existence of a unit root. is a sum of lagged differences of y_t, and ε_t is the error term. The H0: γ=0 (Which means the dataset is non-stationary). The results indicated that the data has a unit root at the level form, confirming the non-stationary nature of the dataset. Therefore, the dataset was first differenced to achieve stationarity as recommended by Nelson & Plosser (1982). Following the first differenced transformation, the time series data became stationary, making it suitable for further examinations by applying econometric models to explore the interlinkages of the BRICS stock markets.

The VAR model is strongly recommended for analysing the datasets that are integrated of order I (1), as it is expected to allow for the existence of both short-run (explained by lagged values) and long-run equilibrium relationships (Johansen & Juselius, 1991). While running the VAR model, the first step is determining the optimal lag length by using AIC, SIC, and HQ criteria (Heino & Anders, 2014). The following are the criterion equations in determining the optimal lag length in a VAR model that balances the trade-off between model fit and complexity:

Akaike Information Criterion (AIC)

$$AIC_{(p)} = -2\ln\ \ln\ (L) + 2p$$

L is the maximum likelihood; *p* is the number of parameters, including lags.

Schwarz Information Criterion (SIC) or Bayesian Information Criterion (BIC):

$$BIC_{(p)} = -2\ \ln\ \ln\ (L)\ + p\ \ln(N)$$

Where, N is the number of observations

Hannan-Quinn Criterion (HQ)

$$HQ_{(p)} = -2\ln\ \ln\ (L)\ + 2p\ \ln(\ln\ \ln\ (N)\ )$$

HQ is a middle point between AIC and BIC.

A smaller value indicates a better model.

The following is the general form of the VAR model.

$$Y_{(t)} = c + \sum_{(i=1)}^{p} A_i Y_{t-i} + \varepsilon_t$$

where, Y_t is a vector of *k* time series variables, C is the constant term, and Ai is A *k* x *k* matrix of coefficients for the *i*th lag. ε_t is the error term, and p is the lag order of the VAR model, signifying how many past observations are included (Stock & Watson, 2001).

The Johansen cointegration test is applied to determine the number of cointegrating vectors between a set of non-stationary datasets (Johansen, 1988). It is performed by applying the following equation:

$$\Delta Y_t = \prod Y_{t-1} + \sum_{(i=1)}^{(p-1)} \Gamma_i \Delta Y_{t-1} + \varepsilon_t$$

where, is the differenced series (T_t -Y_{t-1}), = α, where, α represents the adjustment speer to the long-run equilibrium, and is a cointegrating vector. is the short-run coefficient matrix. The rank of decides the number of cointegrating relationships. The test involves evaluating the eigenvalues of through two statistics (Johansen & Juselius, 1990):

Trace Statistic $= -T\Sigma_{(i=r+1)}^{k} ln?(1-\lambda_i)$

Table 1. Descriptive Statistics of the World's Major Indices

	Sensex	Moex	SSC	JSE40	BoVespa
Mean	24758.41	1622.393	2594.382	34503.03	60262.56
Std. Dev.	19369.15	951.4299	852.5693	19819.18	33967.8
Skewness	1.031248	0.34393	0.438676	0.246543	0.382107
Kurtosis	3.33548	2.547938	3.66167	1.938004	2.230277
JB Stats	54.03469	8.384204	14.94349	16.96572	14.55916
Prob.	0.00000	0.015114	0.000569	0.000207	0.000689

Source: Desk research

Table 2. ADF Test Results for Unit Root

Variable	Order of integration	Z(t) Value	pvalue
Sensex	1(1)	-16.30913*	0.0000
Moex	1(1)	-15.38029*	0.0000
SSE	1(1)	-15.84626*	0.0000
JSE 40	1(1)	-15.96577*	0.0000
Bovespa	1(1)	-16.38831*	0.0000

Note: 1%, 5%, and 10% critical values are -3.4546, -2.87212 and -2.57248, respectively

Source: Desk research

Trace statistics are expected to test the null hypothesis that there are at most r cointegrating vectors.

Max Eigenvalue Statistics $= -T \ln(1-\lambda_{r+1})$

This test is expected to test the null hypothesis that there are r cointegrating vectors against the alternative r +1. In this case λ_i are eigenvalues, and T is the number of observations.

If there is a cointegration, we are expected to run the Vector Error Correction Model to model the equilibrium relationship (Engle & Granger, 1987; Hamilton, 2020).

$$\Delta Y_t = \alpha(\beta' Y_{t-1}) + \sum_{(i=1)}^{(p-1)} \Gamma_i \Delta Y_{t-1} + \varepsilon_t$$

where, α is the adjustment coefficient, β is the cointegrating matrix, and Γ_{is} coefficient of the short-run relationship. Note that the VECM captures both the short and long run relationship (through $\alpha \beta' Y_{t-1}$).

The Toda-Yamamoto method is applied to test for Granger causality in the presence of a non-stationary dataset of the VAR framework (Toda & Yamamoto, 1995). The following equation is applied to determine the relationship:

$$Y_t = \sum_{t=1}^{p+d_{max}} A_i Y_{(t-i)} + \varepsilon_t$$

Y_t is the vector of the endogenous variable, Ai are the coefficient matrix and ε_t is the error component.

Impulse Response Function: This measures the response of a variable under study in a VAR framework to a one-time shock in another variable under study, while holding all other shocks constant (Sims, 1980). The equation is a derivative of the MA function in the VAR framework.

$$Y_t = u + \sum_{}^{\infty} \Psi\, u_{t-1}$$

where, $(\Psi_i^0) = \phi_1 \Psi_{i-1} + \phi_2 \Psi_{i-2} + \ldots \phi_p \Psi_{i-p}$ represents the impulse response coefficients recursively

Table 3. VAR Lag Selection Criteria

Lag	LogR	LR	FPE	AIC	SC	HQ
0	-13629.8	NA	6.56E+34	94.3582	94.42163	94.38362
1	-11485.9	4198.718	2.81E+28	79.69475	80.07535*	79.84725*
2	-11462.2	45.60421	2.84E+28	79.70372	80.40148	79.98331
3	-11435.6	50.30474	2.80E+28	79.69246	80.70739	80.09914
4	-11413.9	40.1991	2.87E+28	79.71547	81.04757	80.24924
5	-11385	52.64416	2.80E+28	79.68832	81.33757	80.34916
6	-11351	60.65935	2.63e+28*	79.62621*	81.59263	80.41415
7	-11336.1	26.0527	2.83E+28	79.69625	81.97983	80.61127
8	-11301.3	59.83200*	2.65E+28	79.628	82.22875	80.67011

Source: Desk research

Table 4. Johansen Cointegration Test among the BRICS Indices

R	Eigenvalue	Trace Statistics	Critical Value (5%)	Max-Eigen Statistic	Crit Value (5%)	Result
r = 0	0.107244	79.033*	69.819	33.011*	31.876	Co-integrated
r = 1	0.07866	46.022*	47.86	23.840*	27.584	

'r' =no of co-integrating vectors

** Statistically significant at the 5 per cent level*

Source: Desk research

calculated from the VAR, and is the structural shocks.

Forecast Error Variance Decomposition, popularly known as Variance decomposition, measures the proportion of a variable's forecast error variance accredited to shocks in each variable in the VAR system (Diebold, 1998). The h-step-ahead forecast error variance decomposition for variable j is:

$$VD_{j,h}(k) = \frac{\sum_{i=0}^{h-1} (\Psi i, jk)^2 \sigma_k^2}{\sum_{k=1}^{n} \sum_{i=0}^{h-1} (\Psi i, jk)^2 \sigma_k^2}$$

$\Psi_{i,jk}$ are the impulse coefficient of variable j to a shock in variable k, σ_k^2 is the variance of the shock, and h is the forecast horizon.

Data Analysis

Table 1 presents the descriptive statistics for the BRICS major indices. Among BRICS Indices, the Sensex has a mean Adj closing price of 24,758.41 with a standard deviation of 19,369.15, indicating large price swings. Skewness of 1.031 suggests rarer higher prices, and a kurtosis value of 3.34 indicates more extreme values than a standard normal distribution. A Jarque-Bera value of 54.03 ($p<0.001$) confirms the

Table 5. Estimating Long Run Equilibrium Relationship (Least Squares (Gauss-Newton/ Marquardt steps)

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.015756	0.080136	12.67533	0.0000
C(2)	0.05473	0.411303	0.133064	0.8942
C(3)	-1.62982	0.802186	-2.03172	0.0432
C(4)	-0.00302	0.057146	-0.05288	0.9579
C(5)	0.012395	0.026381	0.469832	0.6389
C(6)	-0.17151	0.114966	-1.49183	0.1369
C(7)	0.807977	0.585147	1.38081	0.1685
C(8)	1.612752	1.146502	1.406671	0.1607
C(9)	-0.04541	0.077142	-0.5887	0.5566
C(10)	0.017099	0.040672	0.420404	0.6745
C(11)	0.237985	0.115723	2.056503	0.0407
C(12)	-1.15098	0.58236	-1.9764	0.0491
C(13)	1.441887	1.151	1.252725	0.2114
C(14)	0.054934	0.077213	0.711457	0.4774
C(15)	-0.06143	0.041727	-1.47207	0.1422
C(16)	-0.14925	0.115839	-1.28842	0.1987
C(17)	0.775794	0.593385	1.307405	0.1922
C(18)	0.340755	1.168257	0.291678	0.7708
C(19)	-0.1563	0.076778	-2.03578	0.0428
C(20)	0.040633	0.04072	0.997849	0.3193
C(21)	0.074344	0.083556	0.889748	0.3744
C(22)	-0.73174	0.420498	-1.74018	0.083
C(23)	-1.92894	0.825878	-2.33562	0.0203
C(24)	0.160401	0.056635	2.832179	0.005
C(25)	-0.00269	0.02664	-0.10086	0.9197
C(26)	317.4489	292.5899	1.084962	0.2789

Adjusted R-squared=0.2951, F-statistic=2371.947, Prob (F-statistic)=0.0000, Durbin-Watson stat=2.001356

Source: Desk research

non-normality with heavier tails. The Moex (Russian) average adj. the closing price was 1,622.39 with a lower volatility of 951.43. It has a slight positive skewness with 0.344, and a kurtosis value of 2.55 indicates a near-normal distribution with fewer extremes. The Jarque-Bera test score 8.38 (<0.05) indicates a minor violation of normality. The Chinese premier

index SSC has an average Adj, closing price of 2,594.38 with moderate volatility of 852.57, with a slightly positively skewed 0.439, and a kurtosis of 3.66, indicating more frequent extreme values. The Jarque-Bera value 14.94 ($p<0.01$) confirms non-normality of the distribution. The JSE-40 average price was 34,503.03, with a very high standard deviation of 19,819.18. Skewness of 0.247 indicates slightly right-skewed, and low kurtosis of 1.94 suggests fewer extreme values. The Jarque-Bera value=16.97 ($p<0.01$) confirms non-normality of the data set. The Bovespa has an average Adj. closing price of 60,262.56 with a high volatility of 33,967.8, indicating large price swings. Distribution is slight positive skewness of 0.382, and kurtosis of 2.23, suggesting fewer extreme values. The Jarque-Bera value 14.56 ($p<0.01$) confirms non-normality of the distribution (Jarque & Bera, 1980).

The Augmented Dicky-Fuller test was used to investigate the presence of a unit root in the collected dataset, determining whether the data series was stationary (Dickey & Fuller, 1979). At the level, unit roots were found in all indices; the table above shows the first-differenced values. After first differencing the data set, the Z(t) value for Sensex was 16.31, well above the critical values at the 1%, 5%, and 10% levels, indicating that the series is free from unit roots (Enders, 2008). Similarly, for Moex (Russian index) Z(t) value was 15.38 was well above the critical values, suggesting the series is stationary after the first difference. For SSE, the index shows a Z(t) value of 15.85, again well above the critical values, confirming it is now free from unit roots. JSE 40 index, the Z(t) value was 15.97, well above the critical values at the 1%, 5%, and 10%, indicating that the series is free from unit roots, and finally, the Bovespa index has a Z(t) value was 16.38 was well above the critical values, indicating no unit root in the differenced series. Each index was tested for stationarity with an intercept, trend, and none, ensuring comprehensive results across different model specifications.

Since the time series variables are integrated of order 1(1), it is appropriate to investigate the cointegration (a long run equilibrium relationship among the variables) among them within a Vector Autoregression framework (VAR). To identify the cointegrating vector(s), a Johansen cointegration test is recommended by Johansen (1988); Johansen & Juselius (1990). Furthermore, the VAR model's performance and drawing inference from the results are highly sensitive to lag selection because choosing an incorrect lag length can lead to biased estimates (Lütkepohl, 2005). In addition, selecting too few lags can omit relevant information, resulting in autocorrelated residuals, while too many lags may overfit the model, increasing estimation errors in parameters and reducing the predictive ability of the model (Enders, 2008). Thus, information criteria such as the AIC, SCI, and HQC are widely recommended for determining optimal lag length selection (Enders, 2008; Hamilton, 2010)

Selecting too few lags can omit relevant information, resulting in autocorrelated residuals, while too many lags may overfit the model, increasing parameter estimation errors and reducing predictive power (Enders, 2008). Thus, information criteria such as the Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ) are widely recommended for determining optimal lag length, balancing model fit with parsimony (Hamilton, 2010). These considerations make lag selection a critical component in

the VAR framework for capturing accurate interdependencies among variables.

Lag selection in VAR models relies on several recommended criteria to determine the optimal lag length that balances model fit and parsimony. The following are the key criteria generally recommended: (i) Akaike Information Criteria (Akaike, 1974), Schwarz Criterion (SC) (Schwarz, 1978), and Hannan-Quinn Criterion (HQ) generally recommended for larger datasets (Hannan & Quinn, 1979). It is evident from the above table that the optimal lag selection for the present study was lag 6 as per AIC and FPE. However, HQ and SC recommend lag 1. There is a contradiction among the various criteria in lag selection. This is quite common in VAR modelling because each criterion balances model fit and complexity differently, leading to diverse recommendations. According to Enders (2008), AIC and FPE are more likely to select higher lags to optimise predictive ability, therefore, we are going ahead with AIC and FPE criteria.

The Johansen cointegration test was conducted among the BRICS indices to determine if there exists a long-run equilibrium relationship among them. This test covers two prominent statistics: Trace statistic and the Max-Eigen statistic, each evaluated against their respective critical values as follows:

At r=0, the trace statistic is 79.033, which is greater than the critical value 69.819, and the Max-Eigen statistic is 33.011, surpassing the critical value of 31.876. Since both values are statistically significant at the 5% level, this indicates the rejection of the null hypothesis, suggesting the presence of at least one cointegrating vector among the BRICS indices. At r=1, the trace statistic is 46.022, which is less than the critical value 47.86, and the Max-Eigen statistic is 23.84, which is also below its critical value of 27.584, indicating that we fail to reject the null hypothesis at this level. The test results imply that there is no evidence for more than one cointegrating relationship.

Based on the results, we concluded that there exists a single cointegrating vector among the BRICS indices, meaning that these indices share a stable relationship. However, it does not by itself provide the dynamics of the long-run or short-run relationships among the indices. Therefore, the Vector Error Correction Model (VECM) is employed to investigate the long-run and short-run relationships among the indices.

The VECM results revealed that the coefficient for the first lag (β=1.015, t=12.68) was significant, the second lag (β=-0.1715, t=-1.49) was not significant, the third lag (β=0.2379, t=2.056) was significant, lag four (β=-0.149, t=1.288) was not significant, and lag five (β=0.0743, t=0.8897) was not significant. The VECM results indicate that Sensex's current value is influenced by its first and third lags, subsequent lags have mixed impacts and lower statistical significance. The SSC's only third lag (β=-1.15, t=1.9764) has a significant impact on Sensex value (possibly due to interdependence between Asian markets), other lags have very little or weaker statistical explanatory power. The VECM results suggest that the immediate past MOEX (-1) (β=-1.6298, t=2.031) and the five-period lag MOEX (-5) (β=-1.9289, t=2.3356) of MOEX exert a significant negative influence on Sensex. This implies that certain immediate and delayed adjustments in the MOEX market conditions have a significant impact on the Indian stock market, possibly due to global economic factors. The other lags of MOEX (-2), (-3), and (-4) show no statistical impact on Sensex. The JSE-40 lag four

(β=-0.1563, t=2.03578) and lag 5 (β=0.1604, t=2.8322) appear to have statistically significant effects on Sensex, with JSE-40 (-4) contributing a negative and JSE-40 (-5) contributing a positive impact on Sensex. However, the first three lags of JSE-40 show either weak or no statistically significant impact on Sensex. However, none of the lags of Bovespa show a statistically significant impact on Sensex based on the t-statistics. The coefficients, although varied, are too small, and the t-values do not exceed the threshold for statistical significance for every lag, suggesting no meaningful relationship.

The Sensex coefficient for C (1) is 1.016, which is positive and statistically significant (β=1.016, t=12.675, p=0.000). The positive sign indicates that Sensex tends to persist at its previous level, implying a non-mean-reverting behaviour. This indicates that the Indian stock market index, Sensex, is not cointegrated with the other BRICS members. If the variables are cointegrated, the coefficient reflects the adjustment mechanism that confirms the variables move back toward their long-term equilibrium relationship after experiencing short-term fluctuations (Engle & Granger, 1987; Pesaran & Shin, 1995; Maddala, 1998). The Past value of the MOEX index (β=-1.6298, t=-2.0317, p=0.0432) has a negative impact on the Sensex. The third lag of Sensex (-3) positively influences the current value (β=0.237985, t=2.056503, p=0.0407). Similarly, past values of SSC (-3) (β=-1.151, t=-1.9764, p=0.0428) have a negative effect on Sensex. The fourth lag of JSE-40 (-4) also negatively impacts Sensex (β=-0.1563, t=-2.0358, p=0.0428). The fifth lag of MOEX (-5) also negatively impacts Sensex (β=-1.9289, t=-2.3356, p=0.0203), and the fifth lag of JSE-40 (-5) positively impacts Sensex (β=0.1604, t=2.832, p=0.005). Therefore, the results confirm that Sensex's current value is significantly influenced by the third lag, while other BRICS indices also contribute as independent variables in the model.

Table 6. Wald Test Results

Test Statistics	Value	df	P
F	133.107	(24, 266)	0.0000
Chi-Sq	3194.568	24	0.0000

Source: Desk research

Table 7. VAR Granger Causality/ Block Exogeneity Wald Test

Excluded	Chi-Sq	df	P
SSE	6.905	2	0.0317
MOEX	6.676	2	0.0355
JSE	1.465	2	0.4807
Bovespa	0.470	2	0.7904
All	14.133	8	0.0784

Source: Desk research

The Wald test results show a significant model effect, $F(24, 266) = 133.107$, $p<0.001$, indicating that the model is statistically significant. The $\chi^2(24) = 3194.57$, $p<0.001$, further confirms the overall significance of the model. The test results indicate that the model, including all the variables and their lags, is highly significant in explaining the change in Sensex. The rejection of the null hypothesis reinforces the relevance of the included independent variables and their lags (Wald, 1943; Wooldridge, 2010).

Diagnostic Checking

A diagnostic check was made by running the various residual tests. First was a correlogram of Q-statistics (Ljung-Box test) to capture whether the VAR model has adequately captured the autocorrelation structure of the

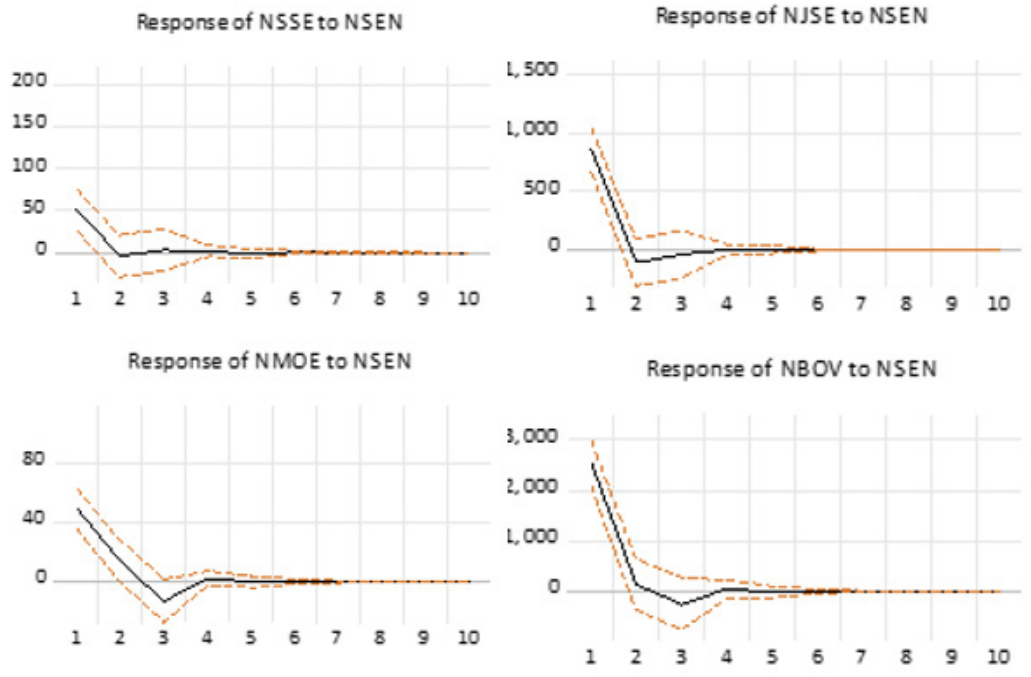


Figure 1. Impulse Response Function.
Source: Desk research

data. The p value for the proposed model is greater than 0.05, indicating that there was no significant autocorrelation in the residuals at the tested lags (Ljung & Box, 1978; Enders, 2008). For the second test, the correlogram of squared residuals, the pvalues are greater than 0.05, indicating that there was no significant evidence of heteroscedasticity in the residuals at the tested lags (Engle, 1982; Brooks, 2019). For the third residual test, the Jarque-Bera test stats was 116.023 with a p-value of 0.000 (<0.001) signifies that the residuals deviate significantly from normality, suggesting the presence of non-normality in the model's errors (Jarque-Bera, 1980; Brooks, 2019). In order to investigate the existence of serial correlation in the data set, the researchers have employed the Breusch-Godfrey Serial Correlation LM test. The F (2, 264) = 0.9548, p= 0.2203 (>0.05) and the Obs*R-squared=0.4941, p=0.2143 (>0.05) both fail to reject the null hypothesis, suggesting that the model residuals do not exhibit autocorrelations (Breusch, 1978; Godfrey, 1978). Finally, the ARCH test was conducted to investigate the existence of homoskedasticity of the time series data. The ARCH F (1,289)=0.64905, p=0.5267 and Obst*R-squared=0.27518, p=0.5108 (>0.05) both fail to reject the null hypothesis. This suggests that the variance of the residuals is homoscedasticity, supporting the assumptions of constant variance across observations (Engle, 1982). In the residual diagnostic checks, all tests indicated satisfactory results, except for

Table 8. Variance Decomposition of Sensex

Period	S.E.	NSEN	NSSE	NMOE	NJSE	NBOV
1	1395.73	100.0000	0.0000	0.0000	0.0000	0.0000
2	1410.62	97.9357	0.0038	2.0136	0.0000	0.0469
3	1431.58	95.4833	1.8617	2.1281	0.3042	0.2227
4	1432.13	95.4517	1.8618	2.1269	0.3370	0.2225
5	1432.72	95.3734	1.8738	2.1768	0.3369	0.2391
6	1432.77	95.3665	1.8768	2.1779	0.3376	0.2411
7	1432.81	95.3623	1.8780	2.1795	0.3383	0.2419
8	1432.81	95.3616	1.8782	2.1798	0.3383	0.2421
9	1432.81	95.3613	1.8782	2.1800	0.3383	0.2421
10	1432.82	95.3613	1.8782	2.1800	0.3383	0.2422

Source: Desk research

the normality of the residuals, which showed a significant deviation from normality.

In the next phase, the short-run causal dynamics within the VAR framework, tools such as Granger causality, Impulse response function, and variance decomposition offer meaningful insights to the short-run relationship. The lag selection criteria record the lowest values for AIC, FPE, and HQE, for lag 1, indicating it as the optimal lag for this model. These criteria aim to balance goodness of fit and model complexity, favouring simpler models when performance is comparable.

Granger causality tests help determine if past values of one variable significantly predict another, identifying short-run directional relationships without establishing a long-run equilibrium (Granger, 1969; Sims, 1980). SSE χ^2=6.905, p=0.0317 (<0.05) and MOEX χ^2=6.676, p=0.0355 (<0.05) display statistically significant causality on the dependent variable (BSE Sensex), indicating that their past values have predictive power for movements in Sensex. This suggests short-run causal linkages, indicating that changes in these markets influence Sensex dynamics. However, JSE-40 χ^2=1.465, p=0.4807 (>0.05) and Bovespa χ^2=0470, p=0.7904 (>0.05) do not significantly Granger-cause Sensex, indicating their past values lack predictive power for Sensex. These results suggest a weaker short-run causal relationship between these variables and the Sensex. The combined effect of all the predictors is marginally non-significant χ^2 = 14.133, p=0.0784 (>0.05), signifying that while individual markets like SSE, MOEX have a causal relationship, the collective contribution of all variables together does not strongly predict Sensex. The findings seem to agree with the literature on financial cointegration and interdependence in global equity markets (Granger, 1969; Sims, 1980). Non-significance of others like NJSE and Bovespa suggest regional variations in influence (Bekaert & Harvey, 1995; Eun & Shim, 1989), possibly due to differing market structure or economic conditions (Chen *et al.*, 1986; Forbes & Ribbon, 2002; Brooks & Del Negro, 2004).

The impulse response function analysis reveals that shocks from different stock markets have varying durations of influence on the Sensex. Specifically, a shock from the SSE to the Sensex lasts for 9 days, the JSE-40 to the Sensex for 6 days, the MOEX for 7 days, and the Bovespa for approximately 7.5 days. These results suggest that the Sensex experiences short-run responses to external market shocks, with the SSE having the most prolonged influence. The above results exhibit the complex interlinkage of global stock markets and the varying extent to which shocks from different regions can affect emerging markets like India. These findings seem to agree with the earlier research studies (Bekaert & Harvey, 1995; Eun & Shim, 1989; Forbes & Ribbon, 2002)

The variance decomposition results of Sensex reveal that it explains most of its variance, consistently accounting for around 95.36% to 97.94%, that is, starting at 100% in period 1 and stabilising at 95.36% by period 10. The Russian MOEX exerts the most external shock 2.18%, followed by SSE 1.88%, while South African Index JSE-40 accounts for 0.34%, and Brazil's Bovespa accounts for -0.24% have negligible impact on the volatility of Sensex, indicating a low degree of interdependence between Sensex and the BRICS nations in the short to medium term. Particularly, the spillover influence of BRICS markets such as NJSE40 and Bovespa remains consistently low (about 0.34% and 0.24%, respectively) across the study periods, which suggests limited spillover effects from these markets on the Sensex during this time. This analysis confirms that the Sensex is driven by its internal dynamics, which limits the impact from BRIC markets. These results may indicate a relatively low level of market integration or weaker financial linkages between the Sensex and BRICS stock markets during the period under review. These findings align with the earlier studies that suggest emerging market indices like the Sensex can often exhibit stronger self-driven volatility compared to Western higher-integrated stock markets (Forbes & Rigobon, 2002; Sharma *et al.*, 2011; Singh *et al.*, 2022).

Diagnostic Checking

After investigating short-run VAR models, it is vital to investigate diagnostic checks to ensure the model's robustness. The first test conducted was VAR Residual Portmanteau Tests for Autocorrelations. The results revealed, the values of Q-Stat (33.665) and Adj Q-Stat (33.99) with p=0.115 and 0.108, respectively, suggest that there was no significant autocorrelation at the 5% level. These results indicate that the error terms are not serially correlated (Kilian & Lutkepohl, 2017). The second test conducted was the VAR residual serial correlation LM Test to investigate the presence of autocorrelation in the errors at different lags. For lag 1, the LRE stats=8.42, p=0.1452, indicating no autocorrelation, while for lag 2, the LRE stats=9.32, p=0.2341, and at lag 3, the LRE stats=31.36, p=0.1772 indicate no significant autocorrelation in the data set. The third diagnostic check conducted was the VAR residual heteroskedasticity test, which reveals non-significant heteroskedasticity in the residuals. The joint test has a Chi-square statistic of 21.34 (df=300), p=0.3542, indicating no evidence of heteroskedasticity in the dataset. At the individual level, most variables do not exhibit significant Chi-square statistics with a pvalue above 0.05, confirming the absence of heteroskedasticity in both their levels and interactions. Finally, the VAR residual normality test indicates a clear rejection of the null

hypothesis that the residuals are multivariate normal. For individual components, both skewness and kurtosis exhibit significant Chi-square statistics with p value well below 0.05, suggesting deviation from normality. The joint tests for skewness, kurtosis and the combined Jarque-Bera statistic further confirm the overall non-normality of the residuals, with all p values being 0.000.

Discussion and Conclusion

The current study examines the stock market indices (Sensex, MOEX, JSE-40, SSE, and Bovespa) interlinkages among the BRICS nations, using data spanning from January 2000 to September 2024. The analysis employed a vector autoregressive framework, as we found a unit root at the level. The study findings offer significant insight into the dynamic interrelationships between the Indian stock market (BSE Sensex) and the BRICS stock indices. The Johansen cointegration test results indicate the existence of a single cointegrating vector among the BRICS stock market indices, suggesting a long-run equilibrium model. This suggests that the stock markets of BRICS nations share common underlying trends, due to global economic conditions or shared macroeconomic factors. However, the coefficient of the error term or error correction term indicates a non-mean-reverting behaviour for the BSE Sensex, indicating that deviations from the equilibrium do not strongly adjust back in the long run. The findings also show that Sensex operates largely independently, driven primarily by its internal dynamics. Our findings seem to agree with the findings of Sharma *et al.* (2011); Tripathi & Sethi (2012) in their study found no evidence of cointegration among the markets, indicating that BRICS countries do not share a common stochastic trend. The limited long-run relationship may reflect structural differences in economic environment, market regulations, and investor behaviour across BRICS nations. Furthermore, Forbes & Rigobon (2002); Singh *et al.* (2022) emphasise that emerging markets, such as the BSE Sensex, often display weaker synchronisation with global stock markets compared to other developed stock markets. They also concluded that while BRICS markets may share certain common influences, the unique dynamics of each economy are the chief drivers of their long-run trends. However, in the short run, the MOEX shows a significant negative impact on Sensex at immediate past values (lag -1) and five period lag values (-5), suggesting that short-term adjustments in the Russian stock market affects Sensex negatively. This could be due to global economic factors or geopolitical influences. Similarly, the third lag of SSE exerts a significant negative effect on Sensex, emphasising the influence of the SSE on Indian premier index. On the other hand, the JSE-40 index exhibits a mixed bag of short-run impacts, with significant positive and negative coefficients at lags -5 and -4, respectively. The lack of significant effect from Brazilian index Bovespa exhibits a weaker linkage between the Indian premier indexes. The Granger's test reveals that the MOEX and SSE indices Granger-cause Sensex, indicating the predictive power of past values of SSE and MOEX on Sensex. On the other hand, indices like JSE-40 and Bovespa did not exhibit significant short run causality with Sensex, signifying limited direct influence. The findings revealed that BSE Sensex is more sensitive to certain BRICS indices, exhibiting the economic and financial interdependencies designed by trade, investment, and geopolitical factors. In addition, the Indian stock market is generally influenced by globally dominant

markets such as MOEX and SSE than by the relatively less interconnected markets within BRICS. The Impulse Response Function (IRF) further supports these findings, displaying varying lengths of shocks from BRICS indices on Sensex. SSE shocks persist for 9 days, MOEX for 7 days, JSE-40 for 6 days, and Bovespa for 7 days. These results confirm the limited short-run spillover effects from BRICS indices on Sensex and Sensex adjust very quickly to external influences but do not retain their effects long term. The variance decomposition results demonstrate that Sensex is mainly influenced by its own internal factors, consistently explaining over 95% to 97.94% of its variance. External shocks from MOEX (approximately 2.18%) and SSE (1.88%) have some influence. However, the impact of JSE-40 (0.34%) and Bovespa (-0.24%) is negligible. These findings highlight a low level of market integration between Sensex and BRICS stock indices, signifying that the Indian stock market functions with relative independence.

The study confirms that while there exists a long-term equilibrium relationship among the BRICS premier indices, the Indian stock market is chiefly self-driven, with limited interdependence on other BRICS stock markets. Furthermore, the study confirms a relatively low degree of market integration among BRICS, exhibiting regional economic structure and trade interdependence. Policymakers and investors should consider the limited spillover effects and dominance of internal market dynamics when framing strategies. Future research could possibly explore sectoral linkages and the role of macroeconomic factors in determining these relationships, further enhancing our understanding of financial integration in the BRICS context. Policymakers, on the other hand, must identify the potential vulnerabilities to external shocks, particularly from significant global players like Russia and China, and formulate strategies to increase market resilience by framing robust fiscal and monetary policies. Trade conflict and diversification of supply chains have reduced Chinese dominance over Indian markets. The current study presents evidence that contradicts the assumptions of a long-term equilibrium relationship among BRICS stock markets, stressing India's relatively self-driven internal dynamics. This suggests the need for further research into the effects of policy interventions, external shocks, and the emerging role of technological advancements and post-pandemic financial trends in determining market interdependence.

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