Stock Market Volatility Transmission and Interlinkage: Evidence from BRICS

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Received April 10, 2021; Revised September 16, 2021; Accepted September 26, 2021

Abstract No isolated financial markets are available due to global financial integration through trade liberalization and FDI presence. Therefore, financial markets are subject to response to home economy events and pair economy movements. The study's motivation is to investigate the volatility transmission and interlinkage between financial markets in BRICS nations from January 01, 2001 to December 31, 2019. The study applies unit root tests, the test of cointegration, ARCH-GARCH effects, and the Non-granger causality test to expose interlinkages. Results of unit root tests expose variables are integrated in mixed order, i.e., few variables are stationary at a level I (0), and few variables are after first difference I (0). The cointegration test reveals the long-run association available in the empirical model, implying that the long-run BRICS stock markets act in the same direction. Results of ARCH-GARCH (1,1) disclose the presence of volatility persistence in the financial markets. Furthermore, the directional causality under the error correction term discloses that the feedback hypothesis explains the causality among financial markets in BRICS nations in the long run. On the other hand, a similar conclusion also derives from the Non-granger causality test.

Keywords Interlinkages, BRICS, Cointegration, VECM, ARCH-GARCH, Toda-Yamamoto

1. Introduction

Market information and stock market volatility move in the same direction because information relating to the financial market causes market behaviour and investors' perception. Furthermore, financial markets that functioned geographically in different locations can have experienced volatility due to anomalies in other markets due to global financial integration. With international trade, foreign capital flows, technological cooperation, and globalization's effects, financial markets are not isolated from other financial markets located in different nations. Hence, the degree of responsiveness in the financial market, especially the capital market, depends on the home country's macro fundamentals movements and the influences of trading partners' economic fluctuations. Wei, Liu [1] postulate that international financial markets act based on the degree of investment and trade openness and their impact thriving gradually with global integration.

The novelty of this study lies in the following aspects. First, several studies have investigated volatility transmission and interlinkage, focusing on BRICS nations by taking a small period. However, this study considers comprehensive data covering January 01, 2001, to December 31, 2019. In estimation, extended time coverage data produce unbiased and efficient estimation, especially gauging long-run connections.

Second, directional causality considers the critical
assessments for evaluating interlinkage. Literature produces most research concentrated on pair-wise causality test. Conversely, this study performs additional two causality tests, namely the Causality test based on Vector Error Correction Model (VECM) to expose both long-run and short-run causality and the Non-granger causality test proposes by Toda and Yamamoto [2].

Nowadays, the domestic financial market is due to cross-broader capital flows witnessing international integration. Therefore, market performance exposes to international integration. It suggests that by increasing foreign participants in the host economy, either equity participation or/and long-run capital for industrialization, the financial market experiences development pressures in the economy eventually play a critical role in stock market behaviour. Furthermore, the host economy's macro fundamentals also inject market frictions since familiar investors are available in both markets. Simultaneously, it can be volatile and probabilistic even though the stock market is correlated with major macroeconomic indices of the economy. High fundamental macroeconomic principles and a healthy capital market will help to support the stock market. Still, foreign exchange is the secret to changing the stock market's performance in banking and finance in this globalized environment [3].

Over the past decades, volatility transmission and linkage between the domestic and international financial markets attract immense interest among finance researchers, especially market experts. Therefore, a growing number of studies have been performed to expose the association between domestics and international financial markets; see, for instance, [4-12]. Likewise, another line of interlinkage between the financial market and other domestic market segments is also investigated in the empirical literature, see [13, 14].

The relationship between the domestic financial system's various components was affected by liberalization and globalization as they introduced many prospects for better portfolio diversification to investors as risk management techniques. Technological integration enables investors to reshape investments with ample scope of portfolio diversifications. Popular news has been identified empirically as a significant cause of financial market convergence in both inter-and intra-countries. This suggests that any event that had taken place in any financial market is quickly assimilated and effect reflected through a promoted reaction in the international financial market. Globalization led to amplifying the foreign currency market targeting securities dominated and increasing interdependency between the foreign exchange market and stock market behaviour.

As globalization resulted in more integration of financial markets, it is essential for market participants to know how the shocks and volatility are transmitted over time across the markets. Ahlgren and Antell [15] explain that the magnitude of the financial crisis from one economy to another, even though the underlying economies are distinct, is one of the most critical aspects of globalization and the fast transfer of information through markets. Over the past decades, the integration of financial markets worldwide has created immense interest among researchers, financial experts, and policymakers in knowing how financial shocks are transmitted across the markets. Therefore, the strong economic ties between emerging and developed markets become the conductor of contagion. In the connection of stock market volatility transmission and its effects, a growing number of finance scholars including explained the effects on domestic and regional financial markets.

The paper's remaining structure is as follows—section II deals with the presentation of the empirical survey. The study's data and methodology are explained in Section III: empirical model estimations and its interpretation report in Section IV. Moreover, finally, a summary of the study findings exhibit in Section V.

2. Literature Review

It is generally accepted that in recent years, international financial markets have become considerably more integrated. On the other hand, a significant rise in the volume of cross-border transactions in securities and currencies has accompanied the liberalization of financial markets and capital flows in the 1990s. More recently, the cross-border ties of emerging stock markets have been the subject of concern, owing to the fast growth and growing openness of emerging markets and the rapid spread of the financial crisis. Finance scholars, including Bekaert and Harvey [16] and Bekaert, Erb [17], Harvey [18], Harvey [19], posit that emerging economy's financial markets are prone to global integration and performance influences with economic movements as well.

Modelling integration and volatility transmission of financial markets are increasingly gaining the attention of financial analysts, investors, and policymakers globally, emphasizing the relevance of inter-linkages of world markets and unanticipated contagion effects to respective market agents. In this connection, a growing number of empirical studies had performed. Observed volatility transmission effects are visible see, for instance, King and Wadhwan [5], Cheung and Ng [20], Theodossiou and Lee [21], Susmel and Engle [22], Koutmos and Booth [23], Liu and Pan [24]; Chen, Firth [25]; Beirne, Caporale [26].

Fasanya and Akinde [27] perform a study to examine the volatility transmission in the Nigerian financial markets from January 2002 to June 2017 by applying the Diebold and Yilmaz approach. Study findings divulge that insignificant volatility transmission available among all financial instruments. Further, the study exposes asymmetry volatility transmission between the Indian stock market and selected Asian stock markets. In a study,
Singhania and Prakash [28] investigate stock market conditional and unconditional volatility with the presence of efficient market hypothesis in Bombay stock exchange for the period 2000-2011 by executing ARCH and GARCH family estimation. Study findings unveil inefficient stock markets by confirming the presence of serial correlation. Additionally, cross-correlation ascertains market integration between conditional volatility and stock market return. Another study executes by Nath Mukherjee and Mishra [29] considering 12 stock markets in the emerging economy. The study reveals a significant and positive association between stock market volatility in the emerging economy. Similar findings are also available in Sen and Bandyopadhyay [30]. Further evidence is available in Palamalai and Devakumar [31] study. They research the stock market's integration in the developing Asia Pacific region, i.e., India, Malaysia, Hong Kong, Singapore, Taiwan, Japan, China, Indonesia, and South Korea. The analysis uses the cointegration and Vector Error Correction Model to do so. The study recognizes the interdependencies and competitive dynamics between selected emerging capital markets, indicating that there may be restricted long-term diversification benefits from exposure to these markets. Still, there may be short-term benefits due to significant transitional volatility.

Budd [32] executes a study to examine the volatility transmission and cluster effects between the US and Asia Pacific equity markets by applying GARCH and DCC-GARCH. Study findings enlighten the existence of dynamism in the equity market, especially during the financial crisis. Another study is implemented by Kumar and Mukhopadhyay [33] and observes a significant split over effects running from the NASDAQ composite index to other selected stock indexes. Moreover, the Granger causality test discloses unidirectional causality running from the US stock market composite index to the Indian stock market composite index.

In a study, Arivalagan [34] advocates that stock market volatility is subject to information asymmetry. Another researcher, Koutmos and Booth [23], explained in the case of volatility transmission across New York, Tokyo, and London stock Markets financial markets, study findings established asymmetric linkages. Further evidence also observes in Hashmi and Xingyun [35] study. They claimed that financial markets in Southeast Asian countries are more prone to foreign stock market volatility due to significant inter-linkages with foreign financial markets, namely New York and the Tokyo stock exchange.

Another line of empirical findings is available for explaining the stock market behaviour associating with other stock markets. A growing number of empirical studies postulated that domestic stock markets are interlinked with other countries stock markets see, for instance, Wong, Agarwal [36], Narayan, Smyth [37], Chuang, Lu [38], Weber, Puddu [39], Elyasiani, Perera [40] find evidence of linkages between the stock markets under study. Deep Sharma and Bodla [41] perform a study to examine the inter-linkages between stock markets of India, Pakistan, and Sri Lanka by applying VAR and Granger causality for the period 203-2010. Study findings observed the existence of unidirectional causality running from the National Stock Exchange (India) Granger causes Karachi Stock Exchange (Pakistan) and Colombo Stock Exchange (Sri Lanka). In another study, Babu, Harirahan [42] confirm bidirectional causality between researched stock markets in case of testing their interlinkage.

Tripathi and Seth [43] examine stock market interlinkage considering the stock market established in India, Pakistan, Sri Lanka, and Bangladesh by applying ARCH-GARCH, Random Walk. The ARCH-GARCH model reveals that the volatility in countries' stock markets is affected by the volatile behaviour of stock markets of other countries. In a study, Nandy and Chattopadhyay [12] investigate interlinkage and volatility transmission in the Indian stock market and other domestic markets: foreign exchange market, bullion market, money market, and regional financial markets represented by Nikkei of Japan and S&P 500 of USA. The study applies multivariate Vector Auto-regression (VAR) and Dynamic Conditional Correlation-Multivariate-Threshold Autoregressive Conditional Heteroscedastic (DCC-MV-TARCH). Study findings disclose asymmetric effects running from both way, i.e., feedback hypothesis available in explaining directional causality between Indian stock market and other regional stock markets.

In a study, Hashmi and Xingyun [35] observe that financial markets in Southeast Asian countries are more prone to foreign stock market volatility due to significant inter-linkages with foreign financial markets, namely New York and Tokyo stock exchange. However, a growing number of researchers express their negative attitude in explaining the stock market inter-linkage see, for instance, Chan, Gup [44], Chaudhuri [45], Elyasiani, Perera [40], Pan, Liu [46], Shahani, Sharma [13], Worthington, Katsuura [47]. Hoque, Sultana [48] Another line of study that prevails in finance literature is volatility transmission to the emerging Islamic stock Index. In a study, Saadaoui and Boujelbene [14] postulate that volatility transmission is significant in the case of all Islamic financial assets during the financial crisis. That is, investors preferably like to invest in less risky assets like Islamic or classical stock. Similar findings are also available in Shabri Abd. Majid, Kameel Mydin Meera [49], Rahman and Sidek [50], Siskawati [51]. Pal and Chattopadhyay [52] discuss the interdependency between the Indian stock market and other domestic financial markets, including the currency market, the bullion market, monetary market, the international investment market, and foreign exchange markets (FII) containing one regional stock market defined by the Japanese Nikkei, and other stock markets represented for the rest of the world. The results with DCC-GARCH suggest that major asymmetric volatility
spillovers exist between national stock exchanges and foreign stock markets. Related assumptions about the interconnection of the Indian stock market with others are also available in Nandy and Chattopadhyay [12] and Chattopadhyay (2019b).

3. Materials and Methods

In this research, we investigate the possible interlinkages between Brazil, Russia, India, China, and South Africa stock returns, commonly known as BRICS nations see Table 1 Stock price indices of BRICS countries. Representing each country stock market, the study select one stock market from each country that is, the SENSEX as a benchmark of India, the IBOV as the benchmark of Brazil, the RTSI as the benchmark of Russia, the SCHOMP as the benchmark of China, and the JSE as the benchmark of South Africa (see, Table I). The daily closing price level of five stock markets from January 01, 2001, to December 30, 2019, is considered the reference period. In this way, the study utilizes 228 months of returns for investigation. In the empirical investigation, the study performs several econometrical techniques, such as a unit root test for ascertaining variables order of integration, the result of all three unit root test results reports in Table I. Apart from the determination variables order of integration. The result of all hypothesis of “variable is not stationary”, and KPSS test assessment.

Table 1. Stock price indices of BRICS countries

| Country       | Symbol | Index                                                      |
|---------------|--------|------------------------------------------------------------|
| INDIA         | SENSEX | S&P BSE SENSEX                                            |
| BRAZIL        | IBOV   | SAO PAULO SE BOVESPA INDEX                                 |
| RUSSIA        | RTSI   | Russia Trading System Index                                |
| CHINA         | SHCOMP | Shanghai Stock Exchange Composite Index                    |
| SOUTH AFRICA  | JSE    | Johannesburg Stock Index                                   |

Several unit root tests, i.e., Dickey and Fuller [53] and P-P test following Phillips and Perron [54] with the null hypothesis of "variable is not stationary", and KPSS test which is proposed by Kwiatkowski, Phillips [55] with the null hypothesis of "variable is stationary" execute to determine variables order of integration. The result of all three unit root test results reports in Table I. Apart from the conventional unit root test, the study performs the Ng-Perron test proposed by Ng and Perron [56], and the result exhibits in Table IV.

Test of Cointegration

Suppose all the variables in a multivariate model are integrated of order one, i.e., I (1). In that case, the next step is to find out whether they are cointegrated or not using Johansen’s framework. The explanations of this approach are available in Johansen [57] and Johansen-Juselius [58]. According to Johansen [57], the multivariate cointegration model is based on the error correction representation given by:

\[ ΔY_τ = μ + ∑_{i=1}^{q} α_i ΔY_{τ−i} + β Y_{τ−1} + ε_τ \]  

Where Yt is an (nx1) column vector of p variables, μ is an (nx1) vector of constant terms, α and β captured coefficient matrices, Δ is a difference operator, and εt ~ IID(0, ). The coefficient matrix β is known as the impact matrix, and it contains information about the long-run relationships. Johansen’s Methodology requires the estimation of the VAR equation (1). The residuals are then used to compute two likelihood ratio (LR) test statistics that can be used to determine the unique cointegrating vectors of Yt. Considering each stock price indices is considered a dependent variable, the matrix version cointegration is given below.

\[
\left( \begin{array}{c}
ΔSENSEX \\
ΔIBOV \\
ΔRTSI \\
ΔSCHOMP \\
ΔJSE
\end{array} \right) = \left( \begin{array}{c}
β_1 \\
β_2 \\
β_3 \\
β_4 \\
β_5
\end{array} \right) + \left( \begin{array}{c}
ε_1 \\
ε_2 \\
ε_3 \\
ε_4 \\
ε_5
\end{array} \right) + \left( \begin{array}{c}
ΔSENSEX \\
ΔIBOV \\
ΔRTSI \\
ΔSCHOMP \\
ΔJSE
\end{array} \right) \left( \begin{array}{c}
ΔSENSEX \\
ΔIBOV \\
ΔRTSI \\
ΔSCHOMP \\
ΔJSE
\end{array} \right)^{-1} \left( \begin{array}{c}
ΔY_τ \\
ΔIBOV \\
ΔRTSI \\
ΔSCHOMP \\
ΔJSE
\end{array} \right)
\]

Pair-Wise Granger Causality Test

First, assessing directional causality, we perform the standard Granger causality test, proposed by Granger [59] for investigating whether past values of a variable helps predict changes in another variable. In the context of this analysis, the Granger method involves the estimation of the following equations:

\[
SENSEX_t = \beta_0 + \sum_{i=1}^{q} \beta_{1i} SENSEX_{t−i} + \sum_{i=1}^{q} \beta_{1'i} IBOV_{t−i} + \sum_{i=1}^{q} \beta_{1'i'} SCHOMP_{t−i} + \sum_{i=1}^{q} \beta_{1'i''} JSE_{t−i} + \epsilon_{1t}
\]

\[
IBOV_t = \beta_0 + \sum_{i=1}^{q} \beta_{2i} SENSEX_{t−i} + \sum_{i=1}^{q} \beta_{2'i} IBOV_{t−i} + \sum_{i=1}^{q} \beta_{2'i'} SCHOMP_{t−i} + \sum_{i=1}^{q} \beta_{2'i''} JSE_{t−i} + \epsilon_{2t}
\]

\[
RTSI_t = \beta_0 + \sum_{i=1}^{q} \beta_{3i} SENSEX_{t−i} + \sum_{i=1}^{q} \beta_{3'i} IBOV_{t−i} + \sum_{i=1}^{q} \beta_{3'i'} SCHOMP_{t−i} + \sum_{i=1}^{q} \beta_{3'i''} JSE_{t−i} + \epsilon_{3t}
\]

\[
SCHOMP_t = \beta_0 + \sum_{i=1}^{q} \beta_{4i} SENSEX_{t−i} + \sum_{i=1}^{q} \beta_{4'i} IBOV_{t−i} + \sum_{i=1}^{q} \beta_{4'i'} SCHOMP_{t−i} + \sum_{i=1}^{q} \beta_{4'i''} JSE_{t−i} + \epsilon_{4t}
\]

\[
JSE_t = \beta_0 + \sum_{i=1}^{q} \beta_{5i} SENSEX_{t−i} + \sum_{i=1}^{q} \beta_{5'i} IBOV_{t−i} + \sum_{i=1}^{q} \beta_{5'i'} SCHOMP_{t−i} + \sum_{i=1}^{q} \beta_{5'i''} JSE_{t−i} + \epsilon_{5t}
\]
Granger-Causality Test under Error Correction Term

After establishing a long-run association among research variables, we proceed to one step to estimate directional causality under the error correction model (ECM). The Granger causality test is based on the following Vector Error Correction Models (VECM):

\[
\begin{align*}
\Delta \text{InSENSEX}_t &= \delta_1 + \sum_{i=0}^{p-1} \alpha_i \Delta \text{InSENSEX}_{t-i} + \\
\Delta \text{SHCOMP}_t &= \delta_2 + \sum_{i=0}^{m-1} \beta_i \Delta \text{SHCOMP}_{t-i} + \\
\Delta JSE_t &= \delta_3 + \sum_{i=0}^{q-1} \gamma_i \Delta JSE_{t-i} + \omega_t
\end{align*}
\]

Equation (11) can only specify directional causality when SENSEX is a dependent variable in the equation. However, we rewrite the equation (11) into matrix form, where each variable serves as a dependent variable in the equation. See equation (12).

\[
\begin{pmatrix}
\Delta \text{SENSEX}_t \\
\Delta \text{RTSI}_t \\
\Delta \text{SHCOMP}_t \\
\Delta JSE_t
\end{pmatrix} = \begin{pmatrix}
\alpha_{01} & \alpha_{02} & \cdots & \alpha_{0n} \\
\alpha_{10} & \alpha_{11} & \cdots & \alpha_{1n} \\
\alpha_{20} & \alpha_{21} & \cdots & \alpha_{2n} \\
\alpha_{30} & \alpha_{31} & \cdots & \alpha_{3n}
\end{pmatrix}
\begin{pmatrix}
\Delta \text{SENSEX}_t \\
\Delta \text{RTSI}_t \\
\Delta \text{SHCOMP}_t \\
\Delta JSE_t
\end{pmatrix}
\]

Where, \( \alpha_i \) to \( \alpha_n \) represents constant term; \( \theta_{11} \) to \( \theta_{66} \) represent the short coefficients of the models; \( \gamma_1 \) to \( \gamma_8 \) represent coefficients of error correction term; ECT \( (t-1) \) is the long-run coefficient and \( \epsilon_{t} \) to \( \epsilon_{6t} \) represents a white noise error correction term.

Toda and Yamamoto [2] Non-Causality Test

To assess directional causality among stock price indices of BRICS countries, i.e., SENSEX, IBOV, RTSI, SCHOMP, AND JSE., to do so, we follow the framework proposed by Toda and Yamamoto [2], widely known as the Non-causality test. The assumption of exiting the granger causality test, i.e., some jointly zero parameters, are not valid with integrated variables. Therefore, overcoming the existing limitations in the traditional causality test, Toda and Yamamoto [2] proposed a causality test utilizing the Modified WALD test for restriction on a VAR parameter \( k \). The Toda and Yamamoto [2] causality test basis on the idea of Vector autoregressive at level \( P=K+D_{\text{max}} \) with correct VAR order \( K \) and \( d \) extra lag, where \( d \) represents the maximum order of integration of time series.

Toda and Yamamoto's non-causality test, according to Zapata and Rambaldi [60], possess certain advantages over the traditional Granger causality test. First, assessing causality with a non-causality test does not require cointegration properties in the system equation. Second, in the mixed order of variables integration that is either I (0) and/or I (1), the MWALD test can investigate existing causality between variables. We summarized the empirical model into the VAR system in the following equations, where each variable is treated as the dependent variable in the respective equations.

\[
\text{SENSEX}_t = \alpha_0 + \sum_{i=1}^{k} \beta_{11} \text{SENSEX}_{t-i} + \sum_{i=0}^{d_{\text{max}}} \hat{\beta}_{1j} \text{IBOV}_{t-j} + \sum_{i=0}^{d_{\text{max}}} \hat{\beta}_{1j} \text{RTSI}_{t-j} + \sum_{i=0}^{d_{\text{max}}} \hat{\beta}_{1j} \text{SHCOMP}_{t-j} + \epsilon_t
\]

\[
\text{RTSI}_t = \alpha_0 + \sum_{i=1}^{k} \delta_{11} \text{RTSI}_{t-i} + \sum_{i=0}^{d_{\text{max}}} \hat{\delta}_{1j} \text{IBOV}_{t-j} + \sum_{i=0}^{d_{\text{max}}} \hat{\delta}_{1j} \text{SENSEX}_{t-j} + \sum_{i=0}^{d_{\text{max}}} \hat{\delta}_{1j} \text{SHCOMP}_{t-j} + \sum_{i=0}^{d_{\text{max}}} \hat{\delta}_{1j} \text{JSE}_{t-j} + \epsilon_t
\]

ARCH –GARCH Effects

The study used generalized autoregressive conditional heteroskedastic models (GARCH) following Bollerslev [61], which is widely considered to catch the influence of volatility clustering and volatility symmetry in the
conditional variance equation. Autoregressive Conditional Heteroskedasticity (ARCH) models are developed explicitly to predict and predict conditional variances. GARCH is the most favourite paradigm for capturing the symmetry of uncertainty in financial returns. GARCH (1,1) is the most common generalized ARCH specification with conditional normal distribution in empirical studies. The model assumes that weights of past residuals decrease geometrically at a pace estimated by the results.

\[
y_t = \alpha_0 + \beta_1 X_t + \epsilon_t \\
\epsilon_t \sim i.i.d(0, Q_t) \\
Q_t = \omega + \sum_{k=1}^{m} \alpha_k \epsilon_{t-k}^2 + \sum_{k=1}^{p} \beta_i Q_{t-k} \\
\text{where, } \omega_0 > 0 \text{ and } \alpha_i + \beta_i < 1
\]

\(Y_t\) represents the index stock returns, \(Q_t\) is conditional variance, \(\beta_0\) represents the model's coefficient, \(\alpha_i\) is the coefficients of the lagged squared residuals, and \(\beta_i\) is the lagged conditional variance.

### 4. Results

#### 4.1. Descriptive Statistics of Selected Stock Markets

Descriptive Statistics was used for preliminary analysis to study the nature of data. The statistical properties such as Mean, Standard deviation, Skewness, Kurtosis, and Coefficient of Variation (CV) give a brief background about the stock market movement during the study period of January 2001 – December 2019. The Jarque-Bera test is used to analyze the data's normality, whether the variables are normally distributed. Considering the results reported in Table 2, it is observed that the indices are not stable due to the higher level of coefficient of variation. The kurtosis values for IBOV, RTIS, SENSEX SCHOMP, and JSE are less than 3, signifying platykurtic distribution. The probability value of the Jarque Bera test shows that none of the series is normally distributed. The null hypothesis is rejected at a 1 percent level of significance.

|                  | BRAZIL | RUSSIA | INDIA | CHINA | SA  |
|------------------|--------|--------|-------|-------|-----|
| **Panel –A: Descriptive Statistics** |        |        |       |       |     |
| Mean             | 0.0006 | 0.0010 | 0.0006| 0.0002| 0.0005|
| Median           | 0.0007 | 0.0009 | 0.0010| 0.0005| 0.0007|
| Maximum          | 0.1465 | 0.2869 | 0.1774| 0.1056| 0.0707|
| Minimum          | -0.1709| -0.3030| -0.1223| -0.1026| -0.1419|
| Std. Dev.        | 0.0188 | 0.0216 | 0.0152| 0.0170| 0.0128|
| Skewness         | -0.0204| -0.1484| -0.0162| -0.1231| -0.2104|
| Kurtosis         | 8.8895 | 31.4043| 13.5248| 7.5272| 9.7226|
| Jarque-Bera      | 5.686  | 132.263| 18.157 | 7.5272| 9.7226|
| Observations     | 3,934  | 3,934  | 3,934 | 3,934 | 3,934|
| **Panel –B: Pair-wise correlation** |        |        |       |       |     |
| BRAZIL           | 1.0000 |        |       |       |     |
| RUSSIA           | 0.3963 | 1.0000 |       |       |     |
| INDIA            | 0.2721 | 0.3353 | 1.0000|       |     |
| CHINA            | 0.1472 | 0.1433 | 0.1608| 1.0000|     |
| SA               | 0.4056 | 0.5189 | 0.3916| 0.1589| 1.0000|
4.2. Unit Root Test

To establish the order of the integration of the variable, the stationarity test is investigated by applying unit root, including the ADF test proposed by [53], P-P test proposed by [62] with the null hypothesis of data is not stationary. KPSS test proposed by [63] with the null hypothesis of data is stationary. The unit test results are exhibited in Table 3. According to the ADF and PP test, study findings established that variables are stationary after the first difference: I (1) and the test results from KPSS confirmed variables are stationary at the I (0) level.

We also perform the Ng-Perron test following Ng and Perron [56] null hypothesis of data with a unit root. The results of Ng-Perron stationarity exhibits in Table 4. The results ascertain that all the stock price indices are integrated after the first difference, i.e., I (1).

Table 3. Unit root test results

|                  | At level | First difference |
|------------------|----------|------------------|
|                  | ADF      | PP               | KPSS   | ADF      | PP       | KPSS   |
| $B_{CON}$        | 0.061    | 0.281            | 5.583*** | -47.180*** | -64.153*** | 0.191  |
| $B_{CONTND}$     | -1.579   | -1.369           | 0.736*** | -47.195*** | -64.204*** | 0.118  |
| $C_{CON}$        | -1.851   | -1.871           | 2.364*** | -34.608*** | -59.951*** | 0.055  |
| $C_{CONTND}$     | -2.217   | -2.267           | 0.299*** | -34.604*** | -59.944*** | 0.056  |
| $I_{CON}$        | 0.394    | 0.405            | 7.319*** | -60.123*** | -60.070*** | 0.133  |
| $I_{CONTND}$     | -2.813   | -2.844           | 0.630*** | -60.133*** | -60.080*** | 0.026  |
| $R_{CON}$        | -0.430   | -0.331           | 6.027*** | -64.202*** | -64.286*** | 0.102  |
| $R_{CONTND}$     | -2.045   | -1.917           | 0.524*** | -64.199*** | -64.284*** | 0.082  |
| $SA_{CON}$       | -0.648   | -0.537           | 7.583*** | -62.556*** | -63.220*** | 0.042  |
| $SA_{CONTND}$    | -3.401*  | -3.120           | 0.358*** | -62.549*** | -63.211*** | 0.040  |

Table 4. Results of the Ng–Perron Unit Root Test

|                  | MZa | MZt | MSB | MPT |
|------------------|-----|-----|-----|-----|
| SENSEX           | 1.055 | 1.525 | 1.446 | 140.342 |
| ΔSENSEX          | -8.825*** | -2.079** | 0.235* | 2.860** |
| SHCOMP           | -3.625 | -1.269 | 0.350 | 6.785 |
| ΔSHCOMP          | -1210.11*** | -24.594*** | 0.020*** | 0.022*** |
| IBOV             | 0.943 | 0.88142 | 0.933 | 61.256 |
| ΔIBOV            | -72.58*** | -6.015*** | 0.082*** | 0.355*** |
| RTSI             | 0.791 | 1.26868 | 1.603 | 6.477 |
| ΔRTSI            | -11.543** | -6.379*** | 0.197** | 2.142** |
| JSE              | 0.864 | 1.43502 | 1.660 | 15.389 |
| ΔJSE             | -14.428*** | -3.339*** | 0.092*** | 3.978* |

Asymptotic critical values*:
Ng and Perron [56]

|      | 1% | 5% | 10% |
|------|----|----|-----|
|      | -13.80 | -8.100 | -5.700 |
|      | -2.580 | -1.980 | -1.620 |
|      | 0.174 | 0.233 | 0.275 |
|      | 1.780 | 3.170 | 4.450 |

The following estimation deals with the determination of optimal lag for further tests. Likelihood ratio (LR) sequential modified LR test statistic, final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SIC), and Hannan Quinn information criterion (HQIC) are used, which are presented in Table 5. To determine optimal lag for this study, we considered SIC and establish optimal lag as 2, which is also established by HQ.
Table 5. VAR Lag order selection criteria

| Lag | LogL   | LR     | FPE    | AIC    | SC     | HQ     |
|-----|--------|--------|--------|--------|--------|--------|
| 0   | 108.2201 | NA     | 6.53e-07 | -0.052569 | -0.044579 | -0.049734 |
| 1   | 53891.56 | 107402.3 | 8.40e-19 | -27.43141 | -27.38346 | -27.41440 |
| 2   | 54079.98 | 375.768 | 7.73e-19 | -27.51463 | -27.4267* | -27.4834* |
| 3   | 54124.57 | 88.825  | 7.65e-19 | -27.52461 | -27.39756 | -27.47925 |
| 4   | 54152.03 | 54.624  | 7.64e-19 | -27.52586 | -27.35069 | -27.46633 |
| 5   | 54178.02 | 51.644  | 7.64e-19 | -27.52637 | -27.31862 | -27.45266 |
| 6   | 54218.62 | 80.544  | 7.58e-19* | -27.5343* | -27.28661 | -27.44642 |
| 7   | 54235.03 | 32.524  | 7.61e-19 | -27.52994 | -27.24228 | -27.42788 |
| 8   | 54264.28 | 57.899* | 7.60e-19 | -27.53210 | -27.20450 | -27.41587 |

Note: * indicates lag order selected by the criterion; LR: sequentially modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion

4.3. Test of Cointegration

A long-run association test among selected stock price indices was investigated by performing the cointegration test proposed by Johansen [64]. The results of the cointegration test exhibit in Table 6 and offers at least one cointegrated equation available in either test type. These findings suggest long-run relationships among selected stock price indices, supported by Aggarwal and Raja [65].

Table 6. Results of the cointegration test

| Variables            | Test type | No intercept and trend | Intercept, no trend | Linear intercept, no trend | Linear intercept and trend | Quadratic intercept and trend |
|----------------------|-----------|------------------------|---------------------|---------------------------|---------------------------|-------------------------------|
| Brazil-China         | Trace-Stat | 1                      | 0                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 1                      | 0                   | 0                         | 0                         | 0                             |
| Brazil-India         | Trace-Stat | 0                      | 1                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 1                   | 0                         | 0                         | 0                             |
| Brazil-Russia        | Trace-Stat | 1                      | 0                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 0                   | 0                         | 0                         | 0                             |
| Brazil-Sa            | Trace-Stat | 1                      | 1                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 2                   | 0                         | 0                         | 0                             |
| China-India          | Trace-Stat | 0                      | 0                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 0                   | 0                         | 0                         | 0                             |
| China-Russia         | Trace-Stat | 0                      | 0                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 1                      | 1                   | 0                         | 0                         | 0                             |
| China-Sa             | Trace-Stat | 0                      | 1                   | 1                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 0                   | 0                         | 0                         | 0                             |
| India-Russia         | Trace-Stat | 1                      | 1                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 2                      | 0                   | 1                         | 0                         | 0                             |
| India-Sa             | Trace-Stat | 1                      | 0                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 0                   | 0                         | 0                         | 0                             |
| Russia-Sa            | Trace-Stat | 1                      | 1                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 1                      | 2                   | 0                         | 0                         | 0                             |
| Brazil-Russia-China  | Trace-Stat | 1                      | 1                   | 1                         | 1                         | 0                             |
| India-Sa             | Trace-Stat | 0                      | 1                   | 0                         | 0                         | 0                             |
|                      | Eigenvalue | 0                      | 0                   | 0                         | 0                         | 0                             |
### Table 7. Result of pair-wise Granger causality test

| Null Hypothesis                              | Obs | F-Statistic | Prob. | Casualty status |
|----------------------------------------------|-----|-------------|-------|-----------------|
| SHCOMP does not Granger Cause IBOV          | 3933| 0.07658     | 0.9263| Unidirectional B→C |
| IBOV does not Granger Cause SHCOMP          | 32.0212| 0000       |       |                 |
| SENSEX does not Granger Cause IBOV          | 3933| 4.38007     | 0.0126| Bidirectional   |
| IBOV does not Granger Cause SENSEX          | 39.1268| 0000       |       |                 |
| MOEX does not Granger Cause IBOV            | 3933| 1.71160     | 0.1807| Unidirectional B→R |
| IBOV does not Granger Cause RTSI            | 3933| 65.0267     | 000   |                 |
| JES does not Granger Cause IBOV             | 3933| 0.47041     | 0.6248| Unidirectional  |
| IBOV does not Granger Cause JES             | 62.9658| 0000       |       | B→JES          |
| SENSEX does not Granger Cause SHCOMP        | 3933| 10.2111     | 0000  |                 |
| SHCOMP does not Granger Cause SENSEX        | 0.82894| 0.4366     |       |                 |
| RTSI does not Granger Cause SHCOMP          | 3933| 14.8739     | 4.E-07| Unidirectional R→C |
| SHCOMP does not Granger Cause RTSI          | 0.17144| 0.8425     |       |                 |
| JES does not Granger Cause SHCOMP           | 3933| 15.5132     | 2.E-07| Unidirectional JES→C |
| SHCOMP does not Granger Cause JES           | 1.48315| 0.2270     |       |                 |
| RTSI does not Granger Cause SENSEX          | 3933| 4.31313     | 0.0135| Bidirectional   |
| SENSEX does not Granger Cause RTSI          | 11.0237| 2.E-05     |       |                 |
| JES does not Granger Cause SENSEX           | 3933| 4.44152     | 0.0118| Unidirectional JES→I |
| SENSEX does not Granger Cause JES           | 1.12495| 0.3248     |       |                 |
| JES does not Granger Cause RTSI             | 3933| 2.05024     | 0.1288| Unidirectional R→JES |
| RTSI does not Granger Cause JES             | 0.44001| 0.6441     |       |                 |

### Table 8. Long-run and Short-run causality applying VECM

| Causality test | Short-run | Long-run | Remarks |
|----------------|-----------|----------|---------|
| SENSEX         | IBOV      | SCHOMP   | RTSI    | JSE  | ECT| Remarks |
| SENSEX         | 69.107*** | 3.701*   | 0.0196  | 23.333*** | -0.036*** | √ |
| IBOV           | 4.230**   | 0.632    | 0.2057  | 0.082 | -0.071*** | √ |
| SCHOMP         | 3.822*    | 32.110***| 0.9706  | 1.8376 | -0.032*** | √ |
| RTSI           | 9.639***  | 123.314***| 45.576***| 22.051**| -0.018*** | √ |
| JSE            | 0.121     | 144.459***| 4.281**  | 16.990***| -0.011*** | √ |

Note: */**/*** indicates the level of significance at 10%/5%/1%, respectively.

### Table 9. Result of Non-granger causality test –Toda and Yamamoto [2]

| Dependent | SENSEX | IBOV | SCHOMP | RTSI | JSE  | Remarks |
|-----------|--------|------|--------|------|------|---------|
| SENSEX    | -      | 70.225***| 5.397**| 1.03569| 8.174***| IBOV→SENSEX; SCHOMP→SENSEX; JEX→SENSEX; RTSI→IBOV; JSE→IBOV; IBOV→SCHOMP; JSE→SCHOMP; SENSEX→RTSI; SCHOMP→RTSI; JSE→RTSI; |
| IBOV      | 6.850* | -    | 1.2851 | 8.281***| 5.082**|        |
| SCHOMP    | 0.872  | 19.561***| -      | 2.086 | 7.989**|        |
| RTSI      | 12.540**| 132.361***| 5.773* | -    | 20.262***|        |
| JSE       | 12.631**| 170.433***| 2.577  | 16.185***|        |        |

Note: ↔ indicates bidirectional causality and → indicates unidirectional causality. */**/*** specify level of significant at a 10%/5%/1%, respectively.
4.4. Granger Causality Test

The results of the standard granger non-causality test exhibit in Table 7. Study findings unveiled several causalities running among stock returns. Bidirectional causality is running between stock price indices of India and Brazil [SENSEX ↔ IBOV], Russia, and India [SENSEX ↔ RTSI]. Furthermore, unidirectional causality running from Brazil to China [IBOV → SCHOMP], from Brazil to Russia [IBOV → RTSI], from Brazil to South Africa [IBOV → JSE], from India to China [SENSEX → SCHOMP], from Russia to China [MOEX → SCHOMP], from South Africa to china [JSE → SCHOMP], from South Africa to India [JSE → SENSEX] and Russia to South Africa [RTSI → JSE].

Second, the study moves to investigate the causal association among stock returns under the error correction term. The study estimates the prior developed causal association among stock returns under the error correction term. The results of the granger-causality test are reported in Table 8. The coefficient of error correction term \( (ECT_{t-1}) \) ascertain the presence of long run causality in the empirical equation. To specify long-run causality, the coefficients of the error correction term should be negative and statistically significant. It is observable that all the error correction coefficients obtained from empirical model estimation are negative and statistically significant at a 5% level of significance. These findings are suggesting that the long selected stock price indices move together. That is, anomalies in one stock market can influence related market movement in the long run.

Results of short-run causality establish a feedback hypothesis for explaining the causality between Brazil and India [IBOV ↔ SENSEX], china and India [SENSEX ↔ SCHOMP], china and India [SENSEX ↔ SCHOMP] and Russia and South Africa [RTSI ↔ JES], respectively. Furthermore, unidirectional causality running from Russia to India [RTSI → SENSEX], South Africa to India [JES → SENSEX], china to brazil [SCHOMP → IBOV], Russia to brazil [RTSI → IBOV], Russia to china [RTSI → SCHOMP] and south Africa to china [JES → SCHOMP].

Third, the following section investigates directional relation among stock return of BRICS, i.e., SENSEX, IBOV, SCHOMP, RTSI, and JES, by applying the non-granger causality test Toda and Yamamoto [2]. The results of the causality test reports in Table 9. Study findings disclose feedback hypothesis, i.e., bidirectional causality running between brazil and India [IBOV ↔ SENSEX], china and India [SCHOMP → SENSEX], South Africa and India [JEX ↔ SENSEX], Russia and Brazil [RTSI ↔ IBOV], South Africa and Russia [JSE ↔ RTSI], and South Africa and Brazil [JSE ↔ IBOV]. These findings suggest that in the short-run stock market of BICRS might experience market misbehaviour due to related market abnormal behaviour. Furthermore, several unidirectional causalities were found from estimation, such as effect running from Brazil to China [IBOV → SCHOMP], South Africa to China [JSE → SCHOMP], India to Russia [SENSEX → RTSI], and China to Russia [SCHOMP → RTSI].

4.5. ARCH – GARCH Volatility Estimation

A whirlwind of studies on the study of conditional volatility models is strongly inspired by the presence of stylized evidence and core characteristics of volatility, such as volatility clustering, asymmetry of volatility, leveraging impact, and different aspects of time. To evaluate the volatility characteristics, the ARCH's influence in the time series is verified by calculating the LM statistics after obtaining the residual model AR (1). We use residuals on a constant term and historical lagged residual values of the monthly portfolio returns regressed. The option of lag duration, along with the value of log probability, depends on the phase's order that varies before it becomes negligible in the lag values. The results of the ARCH LM test displays in Table 10 and confirms the presence of ARCH effects in the selected market indices.

| Variables | ARCH-LM statistics | P-value |
|-----------|--------------------|---------|
| SENSEX    | 14.315***          | 0.000   |
| IBOV      | 45.215***          | 0.000   |
| SCHOMP    | 15.054***          | 0.000   |
| RTSI      | 11.064***          | 0.000   |
| JSE       | 74.215***          | 0.000   |

The study estimates ARCH-GARCH (1.1) model to evaluate volatility in the equation, and the results exhibit in Table 11. The symmetric GARCH model reveals that all the coefficients are statistically significant at a 1% significance level. These findings are suggesting that volatility persistence in all the variables. Furthermore, the coefficient of ARCH effects (\( \beta \)) and GARCH effects (\( \alpha \)) are unveiled different from zero for all stock market indices that indicate that the lagged value of conditional variance and lagged value of the residuals are capable of precisely predict the future degree of volatility. Moreover, the magnitude of \( \beta \) and \( \alpha \) is relatively close to 1, indicating a high degree of volatility association.
The following section investigates variance, implying that the extended dependent variable explains due to its shocks vis-a-vis the shock of other variables under the study. Hence, it helps to identify each variable's importance, which changes other variables under investigation. Table 12 exhibits the result of forecast error variance of financial markets of BRICS countries.

Results of variance decomposition, hereafter VD, reveals that the stock market in Brazil (about 100%), China (about 91.25%), and Russia (about 97.3%) is quite self-independent, implying that significant percentage variance error in period-1 can be explained by own shocks and leave marginal cope to other financial markets to explain their variance. The stock market in India (about 77.91%) and South-Africa (about 63.35%) forecast error variance can be explained independently. Hence, it is apparent that other trade partners' financial markets immensely influence the stock market in India and South Africa in the short run.

In particular, VD reveals stock market in Brazil can explain 99.47% of error variance for the period 1-10 days, whereas only 0.345% variance can explain by the Indian stock market. Furthermore, it is apparent that in 1-day, SENSEX explains 91.07% ahead of forecast error variance and 81.47% in 10-day ahead of forecast error variance. Likewise, IBOV explains 7.81% and 17.89% of ahead forecast error variance, respectively, for a 1-day and 10-day time horizon. Furthermore, SCHOMP explains 1.117% and 0.465% of ahead forecast error variance for a 1-day and 10-day horizon, respectively. Moreover, the VD of Russia discloses that RTSI explains 77.90% of ahead forecast error variance in 1-day and 64.18% of ahead forecast error variance in the 10-day horizon. Similarly, IBOV explains 16.86% and 29.21% of ahead forecast error variance, respectively, for 1-day and 10-day time horizons. Furthermore, SENSEX explains 4.66% and 6.24% of ahead forecast error variance for 1-day and 10-day horizons, respectively. Additionally, the VD of China and discloses that SCHOMP explains 97.83% of ahead forecast error variance in 1-day and 93.03% of ahead forecast error variance in 10-day horizons. Correspondingly, IBOV explains 2.16% and 6.58% of ahead forecast error variance, respectively, for 1-day and 10-day time horizons. However, the result of the VD of South Africa. It is observable that JSE explains 65.35% of ahead forecast error variance in one 1-day and 55.12% of ahead forecast error variance in the 10-day horizon. Similarly, IBOV explains 17.62% and 31.39% of ahead forecast error variance, respectively, for

### Table 11. Results of ARCH-GARCH model estimation

|                  | Brazil | Russia | India | China | South Africa |
|------------------|--------|--------|-------|-------|--------------|
| **Panel-A: Results of ARCH – GARCH (1,1) Model** |        |        |       |       |              |
| SENSEX           | 0.469*** | 0.166*** | 0.385*** | -0.415*** |
| IBOV             | 0.173*** | -0.175** | -0.051*** | 0.091*** |
| SCHOMP           | 1.058*** | -0.061*** | -0.053*** | 0.114*** |
| RTSI             | 0.259*** | 0.410*** | 0.160*** | 1.022*** |
| JSE              | -0.679*** | 0.062*** | 0.219*** | 0.866*** |
| β                | 0.741*** | 0.814*** | 0.816*** | 0.855*** |
| α                | 0.253*** | 0.127*** | 0.172*** | 0.121*** |
| β+α              | 0.994   | 0.941   | 0.988   | 0.976   |
| **Panel-B: Correlation between Conditional Volatilities** |        |        |       |       |              |
|                  |        |        |       |       |              |
|                  | -0.138*** | 1      |       |       |              |
|                  | -0.190*** | -0.007*** | 1      |       |              |
|                  | 0.119**  | 0.001*  | -0.012*** | 1      |
|                  | 0.085*** | -0.071*** | 0.052** | 0.919** | 1      |
| **Panel – C: Correlation Between Standardized Residuals** |        |        |       |       |              |
|                  |        |        |       |       |              |
|                  | -0.234** | 1      |       |       |              |
|                  | -0.100*  | 0.094*  | 1      |       |              |
|                  | 0.441**  | -0.044*** | -0.110** | 1      |
|                  | -0.476*** | 0.005*  | 0.017*  | -0.876** | 1      |

*** specify level of significance at a 1%
1-day and 10-day time horizons. Furthermore, SENSEX explains 7.09% and 7.53% of ahead forecast error variance for 1-day and 10-day horizons, respectively. Besides, RTSI explains 9.18% and 5.69% of ahead forecast error variance for 1-day and 10-day horizons, respectively.

Table 12. Forecasted error variance of BRICS financial markets

| Periods | S.E. | BRA | CNA | IND | RUS | S  |
|---------|------|-----|-----|-----|-----|----|
|         |      |     |     |     |     |    |
| Panel –A: Variance Decomposition of Brazil |
| 1       | 0.0188 | 100.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2       | 0.0266 | 99.898 | 0.004 | 0.067 | 0.017 | 0.018 |
| 5       | 0.0420 | 99.749 | 0.009 | 0.171 | 0.032 | 0.037 |
| 10      | 0.0589 | 99.497 | 0.013 | 0.345 | 0.050 | 0.092 |
| Panel –B: Variance Decomposition of China |
| 1       | 0.015 | 7.812 | 1.117 | 91.071 | 0.000 | 0.000 |
| 2       | 0.021 | 12.841 | 0.804 | 86.318 | 0.020 | 0.015 |
| 5       | 0.035 | 16.169 | 0.579 | 83.241 | 0.047 | 0.031 |
| 10      | 0.049 | 17.894 | 0.465 | 81.473 | 0.099 | 0.067 |
| Panel –C: Variance Decomposition of India |
| 1       | 0.0213 | 16.861 | 0.5748 | 4.660 | 77.902 | 0.000 |
| 2       | 0.0303 | 24.567 | 0.355 | 5.257 | 69.713 | 0.105 |
| 5       | 0.0479 | 28.011 | 0.222 | 5.835 | 65.769 | 0.161 |
| 10      | 0.0674 | 29.216 | 0.166 | 6.242 | 64.184 | 0.190 |
| Panel –D: Variance Decomposition of Russia |
| 1       | 0.016 | 2.169 | 97.831 | 0.000 | 0.000 | 0.000 |
| 2       | 0.024 | 4.338 | 95.464 | 0.049 | 0.069 | 0.078 |
| 5       | 0.038 | 6.044 | 93.646 | 0.106 | 0.104 | 0.104 |
| 10      | 0.054 | 6.587 | 93.034 | 0.140 | 0.131 | 0.106 |
| Panel –E: Variance Decomposition of South Africa |
| 1       | 0.012 | 17.624 | 0.741 | 7.094 | 9.189 | 65.35 |
| 2       | 0.018 | 26.337 | 0.470 | 6.611 | 7.021 | 59.559 |
| 5       | 0.029 | 30.202 | 0.312 | 6.878 | 6.089 | 56.519 |
| 10      | 0.040 | 31.393 | 0.239 | 7.537 | 5.699 | 55.129 |
Next, the results of the IRF of all stock markets report in Table XIII, and graphical representations of IRF exhibit in Figure 1. A unit shock/innovation in SENSEX and RTSI increases IBOV indices from 1-day to 10-day. On the other hand, unit innovation in SCHOMP and JSE results in decreased IBOV indices from 1-day to 10-day. The IRF of SENSEX reports in Panel-B. The study reveals that one unit shock in SCHOMP and IBOV induces a SENSEX increase from day 1 to day 10. Likewise, unit shock in RTSI and JES encourages SENSEX acceleration from 2-day to 10-day, respectively.

Panel –C in Table 13 displays the results of SCHOMP. The study manifests that unit shock in IBOV induces an increase in SCHOMP from day 1 to day 10. Likewise, unit shock in SENSEX, RTSI, and JES encourage SENSEX acceleration from 2-day to 10-day, respectively. Moreover, the results of the IRF of the RTSI report in Panel-D. The study exposes that one unit shock in SENSEX, SCHOMP, and IBOV induces increased RTSI from day 1 to day 10. Likewise, unit shock in JES negatively tempts RTSI from 2-day to 10-day. Finally, the result of the IRF of JSE display in Panel-E. It
is demonstrated that unit shock in SENSEX, SCHOMP, RTSI, and IBOV increases JES from day 1 to day 10.

### Table 13. Generalized IRF for BRICS financial markets

| Period | BRA | CNA | IND | RUS | S |
|--------|-----|-----|-----|-----|---|
| **Panel –A: Generalized IRF of Brazil** | | | | | |
| 1      | 0.018851 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2      | 0.018838 | -0.000181 | 0.000694 | 0.000357 | -0.000278 |
| 5      | 0.018667 | -0.000224 | 0.001026 | 0.000408 | -0.000507 |
| 10     | 0.018270 | -0.000256 | 0.001534 | 0.000536 | -0.000842 |
| **Panel –B: Generalized IRF of Russia** | | | | | |
| 1      | 0.004215 | 0.001594 | 0.014393 | 0.000000 | 0.000000 |
| 2      | 0.006607 | 0.001142 | 0.014345 | 0.000309 | 0.000277 |
| 5      | 0.006779 | 0.001011 | 0.014148 | 0.000454 | 0.000362 |
| 10     | 0.007004 | 0.000863 | 0.013749 | 0.000698 | 0.000588 |
| **Panel –C: Generalized IRF of India** | | | | | |
| 1      | 0.002495 | 0.016752 | 0.000000 | 0.000000 | 0.000000 |
| 2      | 0.004410 | 0.016860 | 0.000540 | 0.000641 | 0.000682 |
| 5      | 0.004632 | 0.016663 | 0.000662 | 0.000638 | 0.000594 |
| 10     | 0.004569 | 0.016445 | 0.000774 | 0.000720 | 0.000550 |
| **Panel –D: Generalized IRF of China** | | | | | |
| 1      | 0.008772 | 0.001620 | 0.004612 | 0.018855 | 0.000000 |
| 4      | 0.011832 | 0.000779 | 0.005346 | 0.017027 | -0.000958 |
| 5      | 0.011790 | 0.000760 | 0.005379 | 0.016965 | -0.000966 |
| 10     | 0.011635 | 0.000660 | 0.005528 | 0.016635 | -0.001011 |
| **Panel –E: Generalized IRF of South Africa** | | | | | |
| 1      | 0.005289 | 0.001085 | 0.003355 | 0.003819 | 0.010184 |
| 2      | 0.007719 | 0.000623 | 0.003274 | 0.002959 | 0.009709 |
| 5      | 0.007427 | 0.000576 | 0.003515 | 0.003022 | 0.009566 |
| 10     | 0.007288 | 0.000486 | 0.003793 | 0.002922 | 0.009332 |

### 5. Findings and Conclusion

Growing IT scope has introduced accelerated financial knowledge transition to investors worldwide. With this knowledge, investors in one country have access to and contribute to the internationalization of the other countries’ stock markets. The internationalization of the financial markets allows investors to spend their funds in their country of preference and not just in their own country. The study's motivation is to explore the possible interlinkages among the stock market of BRICS countries, namely, SENSEX, IBOV, RTSI, SCHOMP, and JSE. The study applies several econometric tools, such as the unit root test, Johansen [64] test of cointegration, pair-wise causality test, causality under Vector Error Correction term (VECM), and non-granger causality test following Toda and Yamamoto [2]. Furthermore, the presence of volatility evaluates by performing ARCH-GARCH(1,1) effect following Bollerslev [61]. The key findings are stated below:

First, the study performs several unit root tests such as ADF test, P-P test, KPSS test, and Ng-Perron test, assessing stock price indices order of integration. The results of the unit root test confirm that variables are non-stationary at the level. After the first difference, all the variables become stationary, which means all the variables are integrated at the first difference, i.e., I(1).

Second, the cointegration test results ascertain the existence of a long-run association among BRICS stock indices. The presence of one cointegrating relationship during the study period shows that the investor will have no or limited benefits if the portfolio is diversified amongst the studied markets. The series will revert to an equilibrium level in the long run, even if they drift apart in the short run. Our findings are consistent with those of Aggarwal and Raja [65], Tripathi and Sethi [66] and Hoque [67], etc., which also suggests that diversification in the stock market will reap no benefits because of the presence of the cointegration factor.

Third, referring to the causality test results and according to the coefficients of error correction term,
specifying that feedback hypothesis, i.e., bidirectional causality running among the BRICS stock market. These findings suggest that the other related markets will guide market movements in any stock market in the long run. Furthermore, the short-run causality test is considered according to the vector error correction model and non-granger causality test. It is apparent that that feedback hypothesis, i.e., bidirectional causality running between Brazil and India [IBOV ↔ SENSEX], China and India [SCHOMP ↔ SENSEX], South Africa and India [JEX ↔ SENSEX], Russia and Brazil [RTSI ↔ IBOV], South Africa and Russia [JSE ↔ RTSI], and South Africa and Brazil [JSE ↔ IBOV]. These findings suggest that in the short-run stock market of BICRS might experience market misbehaviour due to related market abnormal behaviour.

Fourth, the results of ARCH-LM reveal the availability of volatility in the financial markets of BRICS countries. The results model estimation coefficients exhibit statistical significance at a 1% significance level for all five models. Moreover, the coefficient of ARCH and GARCH effects is statistically significant. Their magnitudes' values are close to 1, implying a higher degree of volatility in the stock return of BRICS financial markets.

The findings include a clearer view of BRICS nations' capital market cointegration, which is essential for owners, brokers, and researchers to know whether portfolio diversification through various stock markets would be helpful. A long-run relationship occurs because of one cointegrating equation, which indicates that competition in various sectors would not be advantageous.

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