Universal Journal of Accounting and Finance 9(5): 1142-1158, 2021 http://www.hrpub.org
DOI: 10.13189/ujaf.2021.090524

Stock Market Volatility Transmission and Interlinkage: Evidence from BRICS

Md. Qamruzzaman[1,*], Rajnish Kler[2], M. Theivanayaki[3], Salma Karim[1]

[1]School of Business and Economics, United International University, Dhaka, Bangladesh
[2]Department of Commerce, Motilal Nehru College (E), University of Delhi, India
[3]School of Business Administration, PSGR Krishnammal College for Women, Tamil Nadu, India

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

Cite This Paper in the following Citation Styles

(a): *[1] Md. Qamruzzaman, Rajnish Kler, M. Theivanayaki, Salma Karim , "Stock market volatility transmission and interlinkage: Evidence from BRICS," Universal Journal of Accounting and Finance, Vol. 9, No. 5, pp. 1142 - 1158, 2021. DOI: 10.13189/ujaf.2021.090524.*

(b): *Md. Qamruzzaman, Rajnish Kler, M. Theivanayaki, Salma Karim (2021). Stock market volatility transmission and interlinkage: Evidence from BRICS. Universal Journal of Accounting and Finance, 9(5), 1142 - 1158. DOI: 10.13189/ujaf.2021.090524.*

Abstract No isolated financial markets are available due to global financial integration through trade liberation 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 fundaments movements and the influences of trading partners' economic fluctuations. Wei, Liu [1] postulate that internarial 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 assessment for evaluating interlinkage. Literate produce 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 fundaments 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 stricture 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 Wadhwani [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 Mukhopadyay [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, Hariharan [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, Srilanka, 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 Autoregression (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 is taken 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 test of cointegration for the established long-run association, three causality tests for investigating directional relationship, ARCH-GARCH effects to gauge volatility, and variance decomposition for effects 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

Unit Root Test

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:

$$\Delta Y_T = \mu + \sum_{i=1}^{P-1} \alpha_i \Delta Y_{I-t} + \beta Y_{T-1} + \varepsilon_t \quad (1)$$

Where Yt is an (nx1) column vector of ρ 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.

$$\begin{pmatrix} \Delta SENSEX \\ \Delta IBOV \\ \Delta RTSI \\ \Delta SCHOMP \\ \Delta JSE \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{pmatrix} + \sum_{I=1}^{P} \alpha i \begin{pmatrix} \Delta SENSEX \\ \Delta IBOV \\ \Delta RTSI \\ \Delta SCHOMP \\ \Delta JSE \end{pmatrix}_{t-p} + \beta \begin{pmatrix} SENSEX \\ IBOV \\ RTSI \\ SCHOMP \\ JSE \end{pmatrix}_{t-1} + \begin{pmatrix} \epsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \end{pmatrix} \quad (2)$$

Pair-Wise Granger Causality Test

First, assessing directional causality, we perform the standard Granger causality test, proposed by Granger [59] seeks to determine 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:

$$\text{SENSEX}_t = \beta_0 + \sum_{i=1}^{q} \beta_{1t}\text{SENSEX}_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{IBOV}_{t-1} + \sum_{i=1}^{q} \beta_{1t} RTSI_{t-1} + \sum_{i=1}^{q} \beta_{1t} SHCOMP_{t-1} + \sum_{i=1}^{q} \beta_{1t} JSE_{t-1} + \varepsilon_{1t} \quad (3)$$

$$\text{IBOV}_t = \beta_0 + \sum_{i=1}^{q} \beta_{1t}\text{IBOV}_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{SENSEX}_{t-1} + \sum_{i=1}^{q} \beta_{1t} RTSI_{t-1} + \sum_{i=1}^{q} \beta_{1t} SHCOMP_{t-1} + \sum_{i=1}^{q} \beta_{1t} JSE_{t-1} + \varepsilon_{1t} \quad (4)$$

$$RTSI_t = \beta_0 + \sum_{i=1}^{q} \beta_{1t} RTSI_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{SENSEX}_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{IBOV}_{t-1} + \sum_{i=1}^{q} \beta_{1t} SHCOMP_{t-1} + \sum_{i=1}^{q} \beta_{1t} JSE_{t-1} + \varepsilon_{1t} \quad (5)$$

$$SHCOMP_t = \beta_0 + \sum_{i=1}^{q} \beta_{1t} SHCOMP_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{SENSEX}_{t-1} + \sum_{i=1}^{q} \beta_{1t}\text{IBOV}_{t-1} + \sum_{i=1}^{q} \beta_{1t} RTSI_{t-1} + \sum_{i=1}^{q} \beta_{1t} JSE_{t-1} + \varepsilon_{1t} \quad (6)$$

$$JSE_t = \beta_0 + \sum_{i=1}^{q} \beta_{1t} JSE_{t-1} + \sum_{i=1}^{q} \beta_{1t} \text{SENSEX}_{t-1} + \sum_{i=1}^{q} \beta_{1t} \text{IBOV}_{t-1} + \sum_{i=1}^{q} \beta_{1t} RTSI_{t-1} + \sum_{i=1}^{q} \beta_{1t} SHCOMP_{t-1} + \varepsilon_{1t} \quad (7)$$

Granger-Causality Test under Error Correction Term

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

$$\Delta\text{lnSENSEX}_t = \delta_1 + \sum_{i=1}^{n-1} \alpha \Delta\text{lnSENSEX}_{t-I} + \sum_{i=0}^{m-1} \beta_{1i} \Delta\text{IBOV}_{t-i} + \sum_{i=0}^{j-1} \gamma_{1i} \Delta\text{SCHOMP}_{t-i} + \sum_{i=0}^{k-1} \rho_{1t} \Delta\text{RTSI}_{t-i} + \sum_{i=0}^{z-1} \pi_{1i} \Delta\text{JES}_{t-i} + \emptyset_1 \text{ETC}_{t-1} + \omega_{1t} \quad (8)$$

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).

$$\begin{bmatrix} \Delta\text{SENSEX}_t \\ \Delta\text{RTSI}_t \\ \Delta\text{SHCOMP}_t \\ \Delta\text{IBOV}_t \\ \Delta JSE_t \end{bmatrix} = \begin{bmatrix} \alpha_{01} \\ \alpha_{02} \\ \alpha_{03} \\ \alpha_{04} \\ \alpha_{05} \end{bmatrix} + \sum_{i=0}^{m} \begin{bmatrix} \Delta\text{SENSEX}_t \\ \Delta\text{RTSI}_t \\ \Delta\text{SHCOMP}_t \\ \Delta\text{IBOV}_t \\ \Delta lnJSE_t \end{bmatrix} \times \begin{bmatrix} \beta_{11}\beta_{12}\beta_{13}\beta_{14}\beta_{15} \\ \beta_{21}\beta_{22}\beta_{23}\beta_{24}\beta_{25} \\ \beta_{31}\beta_{32}\beta_{33}\beta_{34}\beta_{35} \\ \beta_{41}\beta_{42}\beta_{43}\beta_{44}\beta_{45} \\ \beta_{51}\beta_{52}\beta_{53}\beta_{54}\beta_{55} \end{bmatrix} + ECT \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix}_{t-1} + \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \\ \omega_5 \end{bmatrix} \quad (9)$$

Where, α_1 to α_8 represents constant term; θ_{11} to θ_{88} represent the short coefficients of the models; γ_1 to γ_8 represent coefficients of error correction term; ECT $_{(t-1)}$ is the long-run coefficient and ε_{1t} to ε_{8t} represents a white nose of 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_{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.

$$SENSEX_t = \alpha_0 + \sum_{i=1}^{k} \beta_{1i} SENSEX_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} SENSX_{t-j} + \sum_{i=1}^{k} \gamma_{1i} \text{IBOV}_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{1j} \text{IBOV}_{t-j} + \sum_{i=1}^{k} \delta_{1i} \text{RTSI}_{vol\,t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} \text{RTSI}_{vol\,t-j} + \sum_{i=1}^{k} \delta_{1i} SCHOMP_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} SCHOMP_{t-j} + \sum_{i=1}^{k} \delta_{1i} JSE_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} JSE_{t-j} + \varepsilon_{1t} \quad (10)$$

$$IBOV_t = \alpha_0 + + \sum_{i=1}^{k} \gamma_{1i} \text{IBOV}_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{1j} \text{IBOV}_{t-j} \sum_{i=1}^{k} \beta_{1i} SENSEX_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} SENSX_{t-j} + \sum_{i=1}^{k} \delta_{1i} \text{RTSI}_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} \text{RTSI}_{t-j} + \sum_{i=1}^{k} \delta_{1i} SCHOMP_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} SCHOMP_{t-j} + \sum_{i=1}^{k} \delta_{1i} JSE_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} JSE_{t-j} + \varepsilon_{1t} \quad (11)$$

$$RTSI_t = \alpha_0 + \sum_{i=1}^{k} \delta_{1i} \text{RTSI}_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} \text{RTSI}_{t-j} + \sum_{i=1}^{k} \beta_{1i} SENSEX_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} SENSX_{t-j} + \sum_{i=1}^{k} \gamma_{1i} \text{IBOV}_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{1j} \text{IBOV}_{t-j} + \sum_{i=1}^{k} \delta_{1i} SCHOMP_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} SCHOMP_{t-j} + \sum_{i=1}^{k} \delta_{1i} JSE_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} JSE_{t-j} + \varepsilon_{1t} \quad (12)$$

$$SCHOMP_t = \alpha_0 + \sum_{i=1}^{k} \delta_{1i} SCHOMP_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} SCHOMP_{t-j} + \sum_{i=1}^{k} \beta_{1i} SENSEX_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} SENSX_{t-j} + \sum_{i=1}^{k} \gamma_{1i} \text{IBOV}_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{1j} \text{IBOV}_{t-j} + \sum_{i=1}^{k} \delta_{1i} \text{RTSI}_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} \text{RTSI}_{t-j} + \sum_{i=1}^{k} \delta_{1i} JSE_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} JSE_{t-j} + \varepsilon_{1t} \quad (13)$$

$$JSE_t = \alpha_0 + \sum_{i=1}^{k} \delta_{1i} JSE_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} JSE_{t-j} + \sum_{i=1}^{k} \beta_{1i} SENSEX_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} SENSX_{t-j} + \sum_{i=1}^{k} \gamma_{1i} \text{IBOV}_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{1j} \text{IBOV}_{t-j} + \sum_{i=1}^{k} \delta_{1i} \text{RTSI}_{vol\,t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} \text{RTSI}_{vol\,t-j} + \sum_{i=1}^{k} \delta_{1i} SCHOMP_{t-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} SCHOMP_{t-j} + \varepsilon_{1t} \quad (14)$$

ARCH –GARCH Effects

The study uses 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.

$$y_t = \alpha_0 + \beta_1 X_t + \varepsilon_t \quad (15)$$

$$\frac{\varepsilon_t}{\emptyset} \sim iid(0, Q_t)$$

$$Q_t = \omega + \sum_{k=1}^{m} \alpha_k \epsilon_{t-k}^2 + \sum_{k=1}^{p} \beta_i Q_{t-1} \quad (16)$$

$$where, \omega_0 > 0 \; and \; \alpha_i + \beta_i < 1$$

Y_t represents the index stock returns, Q_t is conditional variance, β_0 represents the model's coefficient. α_i is the coefficients of the lagged squared residuals, and β_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.

Table 2. Descriptive statistic

	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	3,369	7,437
Observations	3,934	3,934	3,934	3,934	3,934
Panel –B: Pair-wise correlation					
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 stationery. 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
$B_{CON\&TND}$	-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
$C_{CON\&TND}$	-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
$I_{CON\&TND}$	-2.813	-2.844	0.639***	-60.133***	-60.080***	0.026
R_{CON}	-0.430	-0.331	6.027***	-64.202***	-64.286***	0.102
$R_{CON\&TND}$	-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
$SA_{CON\&TND}$	-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%	-13.80	-2.580	0.174	1.780
	5%	-8.100	-1.980	0.233	3.170
	10%	-5.700	-1.620	0.275	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	-27.39676	-27.47925
4	54152.03	54.624	7.64e-19	-27.52586	-27.35806	-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 – India-Sa	Trace-Stat	1	1	1	1	0
	Eigenvalue	0	1	1	0	1

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	
IBOV does not Granger Cause SHCOMP		32.0212	0000		B→C
SENSEX does not Granger Cause IBOV	3933	4.38007	0.0126	Bidirectional	
IBOV does not Granger Cause SENSEX		39.1268	0000		I←→B
MOEX does not Granger Cause IBOV	3933	1.71160	0.1807	Unidirectional	
IBOV does not Granger Cause RTSI		65.0267	000		B→R
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	Unidirectional	I→C
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		R←→I
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	
	SENSEX	IBOV	SCHOMP	RTSI	JSE	ECT_{t-1}	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 casualty running from Brazil to china [IBOV→SHCOMP], 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 equation considering the error correction term. The results of cointegration ascertain the existence of a long-run association among stock price indices representing BIRCS country. 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 % 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 funning 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.

Table 10. Results of ARCH LM test statistics

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 (β) and GARCH effects (α) 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 β and α is relatively close to 1, indicating a high degree of volatility association.

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***	0.840***
α	0.253***	0.127***	0.172***	0.121***	0.131***
β+α	0.994	0.941	0.988	0.976	0.970
Panel-B: Correlation between Conditional Volatilities					
	1				
	-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					
	1				
	-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%

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 disclose 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

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

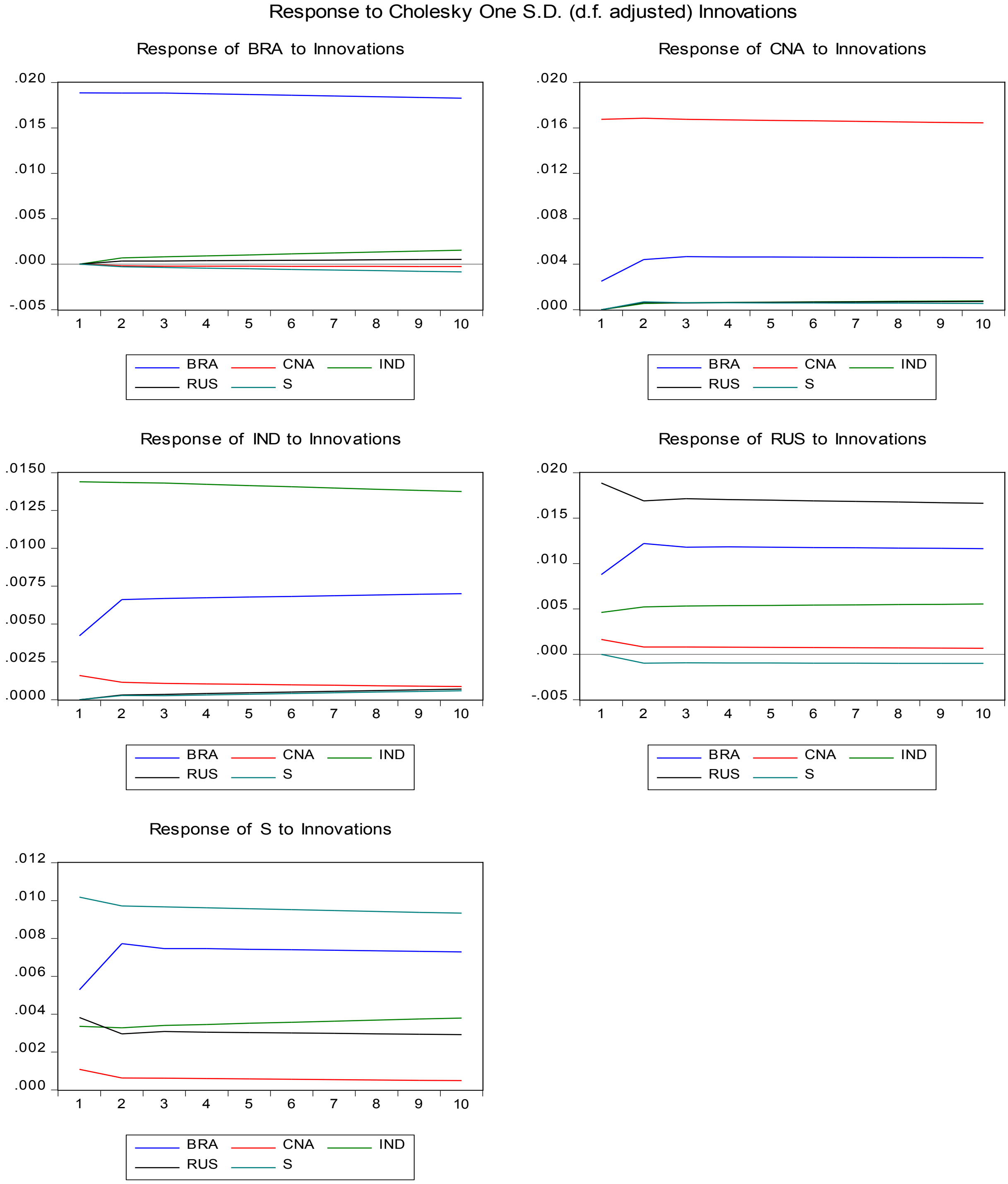

Figure 1. Response to Chloesky One S. D. (d.f. adjusted) Innovations

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.

REFERENCES

[1] Wei, K.J., et al., Volatility and price change spillover effects across the developed and emerging markets. Pacific-Basin Finance Journal, 1995. 3(1): p. 113-136.

[2] Toda, H.Y. and T. Yamamoto, Statistical inference in vector autoregressions with possibly integrated processes. Journal of econometrics, 1995. 66(1-2): p. 225-250.

[3] Gupta, R. and F. Guidi, Cointegration relationship and time varying co-movements among Indian and Asian developed stock markets. International Review of Financial Analysis, 2012. 21: p. 10-22.

[4] Hamao, Y., R.W. Masulis, and V. Ng, Correlations in price changes and volatility across international stock markets. The review of financial studies, 1990. 3(2): p. 281-307.

[5] King, M.A. and S. Wadhwani, Transmission of volatility between stock markets. The Review of Financial Studies, 1990. 3(1): p. 5-33.

[6] Karolyi, G.A., A multivariate GARCH model of international transmissions of stock returns and volatility: The case of the United States and Canada. Journal of Business & Economic Statistics, 1995. 13(1): p. 11-25.

[7] Tanizaki, H. and S. Hamori, Volatility transmission between Japan, UK and USA in daily stock returns. Empirical Economics, 2009. 36(1): p. 27-54.

[8] Throop, A.W., International financial market integration and linkages of national interest rates. Economic Review-Federal Reserve Bank of San Francisco, 1994(3): p. 3.

[9] Helliwell, J.F., Linkages between National Capital Markets: Does Globalization Expose Policy Gaps? 1, in Critical Issues in International Financial Reform. 2018, Routledge. p. 153-174.

[10] Song, W., S.Y. Park, and D. Ryu, Dynamic conditional relationships between developed and emerging markets. Physica A: Statistical Mechanics and its Applications, 2018. 507: p. 534-543.

[11] Law, C.-H., C.-L. Tee, and W.-T. Lau, The Impacts of Financial Integration on the Linkages Between Monetary Independence and Foreign Exchange Reserves. International Economic Journal, 2019. 33(2): p. 212-235.

[12] Nandy, S. and A.K. Chattopadhyay, 'Indian Stock Market Volatility': A Study of Inter-linkages and Spillover Effects. Journal of Emerging Market Finance, 2019. 18(2_suppl): p. S183-S212.

[13] Shahani, R., U. Sharma, and M. Wadhwa, Inter-Linkages Between Movement of the Indian Rupee and BSE Sector-Specific (IT) Index: An Empirical Investigation. IUP Journal of Applied Finance, 2015. 21(3): p. 68.

[14] Saadaoui, A. and Y. Boujelbene, Volatility transmission between dow jones stock index and emerging islamic stock index: case of subprime financial crises. EMAJ: Emerging Markets Journal, 2015. 5(1): p. 41-49.

[15] Ahlgren, N. and J. Antell, Stock market linkages and financial contagion: A cobreaking analysis. The Quarterly Review of Economics and Finance, 2010. 50(2): p. 157-166.

[16] Bekaert, G. and C.R. Harvey, Time‐varying world market integration. the Journal of Finance, 1995. 50(2): p. 403-444.

[17] Bekaert, G., et al., What matters for emerging equity market investments. Emerging markets quarterly, 1997. 1(2): p. 17-46.

[18] Harvey, C.R., Predictable risk and returns in emerging markets. The review of financial studies, 1995. 8(3): p. 773-816.

[19] Harvey, C.R., The drivers of expected returns in international markets. Available at SSRN 795385, 2000.

[20] Cheung, Y.-W. and L.K. Ng, Interactions between the US and Japan stock market indices. Journal of International Financial Markets, Institutions & Money, 1993. 2(2): p. 51-70.

[21] Theodossiou, P. and U. Lee, Mean and volatility spillovers across major national stock markets: Further empirical evidence. Journal of Financial Research, 1993. 16(4): p. 337-350.

[22] Susmel, R. and R.F. Engle, Hourly volatility spillovers between international equity markets. Journal of international Money and Finance, 1994. 13(1): p. 3-25.

[23] Koutmos, G. and G.G. Booth, Asymmetric volatility

transmission in international stock markets. Journal of international Money and Finance, 1995. 14(6): p. 747-762.

[24] Liu, Y.A. and M.-S. Pan, Mean and volatility spillover effects in the US and Pacific-Basin stock markets. Multinational Finance Journal, 1997. 1(1): p. 47-62.

[25] Chen, G.-m., M. Firth, and O.M. Rui, Stock market linkages: evidence from Latin America. Journal of Banking & Finance, 2002. 26(6): p. 1113-1141.

[26] Beirne, J., et al., Global and regional spillovers in emerging stock markets: A multivariate GARCH-in-mean analysis. Emerging markets review, 2010. 11(3): p. 250-260.

[27] Fasanya, I.O. and M.A. Akinde, Volatility transmission in the Nigerian financial market. The Journal of Finance and Data Science, 2019.

[28] Singhania, M. and S. Prakash, Volatility and cross correlations of stock markets in SAARC nations. South Asian Journal of Global Business Research, 2014. 3(2): p. 154-169.

[29] Nath Mukherjee, K. and R.K. Mishra, Stock market integration and volatility spillover: India and its major Asian counterparts. Research in International Business and Finance, 2010. 24(2): p. 235-251.

[30] Sen, S.S. and T. Bandyopadhyay, Characteristics of conditional volatility of BSE SENSEX: The impact of information asymmetry and leverage. South Asian Journal of Management, 2012. 19(4): p. 27-44.

[31] Palamalai, S. and C. Devakumar, Stock market linkages in emerging Asia-Pacific markets. Sage Open, 2013. 3(4): p. 2158244013514060.

[32] Budd, B.Q., The transmission of international stock market volatilities. Journal of Economics and Finance, 2018. 42(1): p. 155-173.

[33] Kumar, K.K. and C. Mukhopadyay, Equity market interlinkages: Transmission of volatility-A case of US and India. NSE, India Research paper, Source: www. nseindia. com, 2002.

[34] Arivalagan, G., Volatility Modeling for SENSEX using ARCH Family. St. Theresa Journal of Humanities and Social Sciences, 2016. 2(2).

[35] Hashmi, A.R. and L. Xingyun, INTERLINKAGES AMONG SOUTH EAST ASIAN STOCK MARKETS (A Comparison Between Pre-and Post-1997-Crisis Periods) 1. 2001.

[36] Wong, W.-K., A. Agarwal, and J. Du, Financial integration for India stock market, a fractional cointegration approach. National University of Singapore Working Paper No. WP0501, 2005.

[37] Narayan, P., R. Smyth, and M. Nandha, Interdependence and dynamic linkages between the emerging stock markets of South Asia. Accounting & Finance, 2004. 44(3): p. 419-439.

[38] Chuang, I.-Y., J.-R. Lu, and K. Tswei, Interdependence of international equity variances: evidence from East Asian markets. Emerging Markets Review, 2007. 8(4): p. 311-327.

[39] Weber, S., S. Puddu, and D. Pacheco, Move it! How an electric contest motivates households to shift their load profile. Energy Economics, 2017. 68: p. 255-270.

[40] Elyasiani, E., P. Perera, and T.N. Puri, Interdependence and dynamic linkages between stock markets of Sri Lanka and its trading partners. Journal of Multinational Financial Management, 1998. 8(1): p. 89-101.

[41] Deep Sharma, G. and B. Bodla, Inter-linkages among stock markets of South Asia. Asia-Pacific Journal of Business Administration, 2011. 3(2): p. 132-148.

[42] Babu, M., C. Hariharan, and S. Srinivasan, Inter Linkages of Asian Pacific Stock Markets: An Empirical Study. Amity Journal of Finance, 2016. 1(1): p. 18-35.

[43] Tripathi, V. and R. Seth, Market Efficiency, Inter-linkages and volatility transmission in stock markets of selected SAARC countries. South Asian Journal of Management, 2016. 23(4): p. 149.

[44] Chan, K.C., B.E. Gup, and M.S. Pan, International stock market efficiency and integration: A study of eighteen nations. Journal of business finance & accounting, 1997. 24(6): p. 803-813.

[45] Chaudhuri, K., Cointegration, error correction and Granger causality: An application with Latin American stock markets. Applied Economics Letters, 1997. 4(8): p. 469-471.

[46] Pan, M.-S., Y.A. Liu, and H.J. Roth, Common stochastic trends and volatility in Asian-Pacific equity markets. Global Finance Journal, 1999. 10(2): p. 161-172.

[47] Worthington, A.C., M. Katsuura, and H. Higgs, Price linkages in Asian equity markets: Evidence bordering the Asian economic, currency and financial crises. Asia-Pacific Financial Markets, 2003. 10(1): p. 29-44.

[48] Hoque, M.Z., N. Sultana, and T. Thalil, Credit rationing's determinants of Small and Medium Enterprises (SMEs) in Chittagong, Bangladesh. Journal of Global Entrepreneurship Research, 2016. 6(1): p. 1-23.

[49] Shabri Abd. Majid, M., A. Kameel Mydin Meera, and M. Azmi Omar, Interdependence of ASEAN-5 stock markets from the US and Japan. Global Economic Review, 2008. 37(2): p. 201-225.

[50] Rahman, A.A. and N.Z.M. Sidek. Spill-over effect of us Sub-prime crisis on ASEAN-5 stock markets. in Business and social science research conference. 2011. World Business Institute Australia Dubai, UAE.

[51] Siskawati, E., Islamic capital market interconnection: An evidence from jakarta islamic index to the regional Islamic market and global islamic market. Jurnal Akuntansi & Manajemen, 2011. 6(2): p. 75-85.

[52] Pal, S.N. and A.K. Chattopadhyay, â€˜ Indian Stock Market Volatilityâ€™: A Study of Inter-linkages and Spillover Effects. Journal of Emerging Market Finance, 2019. 18(2_suppl): p. 183-212.

[53] Dickey, D.A. and W.A. Fuller, Distribution of the Estimators for Autoregressive Time Series with a Unit Root. Journal of the American Statistical Association, 1979. 74(366a): p. 427-431.

[54] Phillips, P.C. and P. Perron, Testing for a unit root in time series regression. Biometrika, 1988. 75(2): p. 335-346.

[55] Kwiatkowski, D., et al., Testing the null hypothesis of stationarity against the alternative of a unit root. Journal of

econometrics, 1992. 54(1-3): p. 159-178.

[56] Ng, S. and P. Perron, Lag length selection and the construction of unit root tests with good size and power. Econometrica, 2001. 69(6): p. 1519-1554.

[57] Johansen, S., Statistical analysis of co integration vectors. Journal of Economic Dynamics and Control, 1998. 10(4): p. 231-254.

[58] Johansen-Juselius, Maximum Likelihood Estimation and Inference on Cointegration – With Applications to the Demand for Money. Oxford Bulletin of Economics and Statistics, 1990. 51: p. 169–210.

[59] Granger, C.W., Investigating causal relations by econometric models and cross-spectral methods. Econometrica: journal of the Econometric Society, 1969: p. 424-438.

[60] Zapata, H.O. and A.N. Rambaldi, Monte Carlo evidence on cointegration and causation. Oxford Bulletin of Economics and statistics, 1997. 59(2): p. 285-298.

[61] Bollerslev, T., Generalized autoregressive conditional heteroskedasticity. Journal of econometrics, 1986. 31(3): p. 307-327.

[62] Phillips, P.C.B. and P. Perron, Testing for a unit root in time series regression. Biometrika, 1988. 75(2): p. 335-346.

[63] Kwiatkowski, D., et al., Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? Journal of Econometrics, 1992. 54(1-3): p. 159-178.

[64] Johansen, S., Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. Econometrica, 1991. 59: p. 1551-1580.

[65] Aggarwal, S. and A. Raja, Stock market interlinkages among the BRIC economies. International Journal of Ethics and Systems, 2019.

[66] Tripathi, V. and S. Sethi, Inter linkages of Indian stock market with advanced emerging markets. Asia-Pacific Finance and Accounting Review, 2012. 1(1): p. 34-51.

[67] Hoque, H.A.A.B., Co-movement of Bangladesh stock market with other markets: Cointegration and error correction approach. Managerial Finance, 2007. 33(10): p. 810-820.