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## Article

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# Return and volatility spillovers between Nigeria and selected stock markets: Evidence from a diagonal BEKK-AMGARCH Model

*Tari Moses Karimo<sup>1</sup>, Abraham Ochoche<sup>2</sup> and Ngozi Victor Atoi<sup>3</sup>*

## Abstract

*The study examines returns spillover, shock, and volatility transmission between Nigeria and selected global stock markets over the period January 2000 to August 2021 using a diagonal BEKK-AMGARCH model. Results show that the Nigerian stock market exhibits characteristics of inefficiency, as investors could consistently make gains higher than the market average. Also, the study observes a positive return transmission between Japan and Nigeria only, suggesting that, investors could benefit from diversification into Nigeria and Japan markets. Except for China and Hong Kong, volatility is relatively more sensitive to bad news indicating that negative information shock heightens market risk more than positive shock due to increased trading activities arising from speculation. The policy implication is that the Nigerian market is less developed and requires improvement in infrastructure/institution to become more developed and integrated to the rest of the world. Also, investors can hedge against loss in Japan by diversifying into Nigeria.*

**Keywords:** Return, information shock, spillover, stock market, transmission, volatility

JEL Classification: G14, G15

## 1. Introduction

Return and volatility spillover among financial assets/markets is key in the portfolio diversification strategy of investors. Similarly, policy decisions in domestic economies could be significantly influenced by these spillovers. Therefore, understanding the sources of return and volatility spillover to domestic markets is significant to investors and policy makers in their

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efforts to diversify investment portfolio and formulate policy, respectively (Liu, 2016; Gruel, 1968; Markowitz, 1952). The level of financial integration among economies is one important source of return and volatility spillover into domestic economies.

Theoretically, combining financial assets with less than perfect positive correlation reduces the level of risk associated with a portfolio without compromising return (Markowitz, 1952). This means that the lower the correlation between the assets in a portfolio, the less risky the portfolio, irrespective of the riskiness of the individual assets. The effect of volatility spillover among asset markets could differ depending on the degree of integration and nature of the shock. More integrated markets are more likely to be affected by external shocks since more trading activities take place among them and bad news is more likely to have greater influence on volatility spillovers due to the inherent behaviour of economic agents to react more and quicker to bad news. This underscores the need to examine return and volatility spillover among financial markets.

Return and volatility spillover among financial markets is a subject of extensive debate in the literature, especially since the proposal of the multivariate approaches to studying volatility (Diebold & Yilmaz, 2009, 2012 and 2014; Kroner & Ng, 1998; Baba *et al.*, 1990; Bollerslev *et al.*, 1988). However, empirical studies focus more on Asian, European, US, and other more developed markets (Mensi *et al.*, 2021; Gamba-Santamaria *et al.*, 2019; Kim & Ryu, 2015; Mohammadi & Tan, 2015; Diebold & Yilmaz, 2014, 2012, and 2009; Natarajan *et al.*, 2014). Very little is known about the link between the Nigerian and other stock markets of the world. To the best of our knowledge, studies on return and volatility spillover between Nigeria and strategic developed markets are scanty, the few that have studied Nigeria focus more on symmetric effect of shock on volatility (Obadiaru *et al.*, 2020; Phume & Bonga-Bonga, 2018).

The empirical literature suggests that several approaches have been used to study return and volatility spillover, especially the family of multivariate GARCH models and the outcomes are similar. The results suggest that volatility spillover intensifies with global crises and more from developed to less developed markets (Mensi *et al.*, 2021; Aslam *et al.*, 2021; Gamba-Santamaria *et al.*, 2019).

The current study examines return and volatility spillover between Nigeria and five selected stock markets and contributes to extant literature in two ways. First, it focuses on one of the largest and more resilient stock markets in Africa (Nigeria stock exchange) on the one hand and selected strategic stock markets [Chinese (CH), Hong Kong (HK), Japan (JP), United

Kingdom (UK), and the United States (US)]. The focus on Nigeria stems from it being one of the largest stock markets in Africa with 156 listed companies and market capitalization of about \$66.7 billion.<sup>4</sup> Also, in recent times the Nigerian stock market has shown strong resilience, especially during the 2007-2009 global financial crisis and the COVID-19 pandemic, making it a worthy candidate for a comprehensive study on international stock market interdependence. In March 2020, returns on the Nigerian stock exchange averaged -8.65% compared to a pre-pandemic position of 3.49%. It, however, became positive in April (3.74%) after the immediate shock from the pandemic and was hardly negative from thereon. Similar pattern was observed between August 2008 and February 2009, during the global financial crisis, when returns on the Nigerian stock exchange was negative but became positive thereafter, and hardly recorded negative values<sup>5</sup>. The US, UK, HK, and JP markets are some of the largest, and arguably the most developed stock markets in the world (Liu, 2016). In 2014, the Nigeria Stock Exchange (NSE) signed a memorandum of understanding (MoU) with the London Stock Exchange Group that allows for dual listing of firms in both markets.<sup>6</sup> While Japan and China were the dominant destinations for foreign exchange demand in Nigeria between 2008 and 2022, the US and UK remained the dominant sources of foreign exchange earnings to Nigeria (Central Bank of Nigeria, 2022). These suggest a strong economic and financial ties between Nigeria and these countries, hence, the choice of these countries.

Second, the study accounts for the influence of asymmetries in information on volatility spillover using a diagonal BEKK (Baba, Engel, Kraft & Kroner) asymmetric multivariate generalized autoregressive conditional heteroskedasticity (BEKK-AMGARCH) model proposed by Kroner and Ng (1998). The modelling approach adopted is to allow for the impact of asymmetries in information shock on volatility since financial time series are known to exhibit asymmetries to information shock. It is more a general way to analysis shock since the rejection of asymmetry reduces to symmetric analysis.

The rest of the study is organized as follow: in Section 2, the study presents the literature review; the methodology is presented in Section 3; Section 4 has the results and discussion; and finally, Section 5, presents the conclusion and recommendations.

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<sup>4</sup><https://sashares.co.za/biggest-stock-exchanges-in-africa/#gs.m8b8j5>

<sup>5</sup> Authors computation based on data drawn from Bloomberg terminal available at [Bloomberg Terminal | Bloomberg Professional Services](#)

<sup>6</sup> <https://www.vanguardngr.com/2014/11/nse-signs-mou-london-stock-exchange/>

## **2. Literature Review**

### **2.1 Theoretical Literature**

Spillovers among financial markets is critical for portfolio diversification and policy decisions. The modern portfolio theory (MPT) provides useful insights on the importance of spillovers among financial markets (Markowitz, 1952 and 1959) and forms the theoretical foundation of this study. The MPT has come under criticism for being oversimplistic (see Tobin, 1958; Kraus & Litzenberger, 1976; Fama, 1968; Elton & Gruber, 1974), nevertheless, it remains the cornerstone of modern portfolio diversification theories. The MPT suggests that the lower the correlation between assets in a portfolio, the less risky the portfolio will be, regardless of the riskiness of the individual assets. The takeaway is that assets are not selected solely based on their individual characteristics, but also on the degree and direction of their co-movements with other assets. The co-movements provide a way of formulating a portfolio with equal expected return and lower risk relative to one constructed based solely on their individual characteristics. By highlighting the importance of the co-movement of returns and risk in portfolio diversification, the MPT allows for evaluation of returns, shocks, and volatility spillovers among returns of financial assets which could be within an economy or among economies.

### **2.2 Empirical Literature**

There exists a huge empirical literature on return and volatility spillover. This study provides a summary of the literature focusing on the two widely used approaches. Studies mostly model return and/or volatility spillover using the MGARCH family of models and the Diebold-Yilmaz interconnectedness index. Following the works of Bollerslev *et al.*, (1988) and Baba *et al.*, (BEKK, 1990) proposing the (D)VECH-MGARCH, the (D)BEKK-MGARCH models the literature on return and volatility spillover has grown tremendously and proposal of the interconnectedness index by Diebold and Yilmaz (2012 and 2014) added more strength to this literature. We learn that irrespective of method used, crisis periods are associated with higher and increasing volatility spillover, that is, the existence of contagion effect. For example, the intensity of volatility spillovers increased with the global financial crisis and the Covid-19 pandemic (Mensi *et al.*, 2021; Gamba-Santamaria *et al.*, 2019; Kim & Ryu, 2015; Mohammadi & Tan, 2015; Diebold & Yilmaz, 2014; Natarajan *et al.*, 2014; Diebold & Yilmaz, 2012).

We also learnt from the literature that volatility spills over from developed to developing/less developed markets, suggesting that developed markets are net transmitters while developing/less developed markets are net recipients of volatility. For example, volatility

spillovers move from the US to the Asian and to the GCC (Bahrain, Oman, Kuwait, Qatar, United Arab Emirates) markets (Lien *et al.*, 2018; Chow, 2017; Mohammadi & Tan, 2015; Alotaibi & Mishra, 2015), from German and Dutch markets to other European markets (Aslam *et al.*, 2021) and from global and regional to domestic markets (Muharam *et al.*, 2019; Bala & Takimoto, 2017). In addition, we learnt that good and bad news have different effects on volatility spillovers (Panda & Thiripalraju, 2018; Majdoub & Sassi, 2017). This strand of literature mainly uses asymmetric versions of the MGARCH family of models.

The literature further suggests that Nigeria and, indeed, West African markets are net recipients of return and volatility spillover (Obadiaru *et al.*, 2020; Obadiaru *et al.*, 2018; Phume & Bonga-Bonga, 2018). This strand of literature uses the MGARCH and exponential GARCH (EGARCH) models. Although, the literature suggests that good and bad news have differential effects on return and volatility spillovers, only Aliyu *et al.*, (2018) in this strand of literature on Nigeria accounts for asymmetries but did not show the relative importance of good and bad news beyond the presence of asymmetries. Their results suggest a bidirectional spillover between developed markets on the hand and Nigeria and South Africa on the other, though, the spillovers from Nigeria and South Africa to developed markets were weak. In addition, Aliyu *et al.*'s analysis for the US is based on the Dow Jones index, which covers only thirty prominent firms listed on the US stock exchanges. This may not be a good proxy for the US stock market where there is the Standard and Poors (S&P) 500 that covers over 500 prominent firms listed on stock exchanges in the US. Thus, the current study adopts the diagonal BEKK asymmetry MGARCH (DBEKK-AMGARCH) to vividly capture the relative impact of good and bad news and uses the S&P 500 to represent the US stock market, hence, it extends Aliyu *et al.*, (2018).

### **3. Methodology**

#### **3.1 Data and Estimation Procedure**

The stock returns considered are those of the US Standard & Poors 500 (US), the UK Financial Times Stock Exchange (UK), the Chinese Shanghai (CH), Japanese Nikkei (JP), Hong Kong Hang Sheng (HK), and the Nigeria all share index (NG). Data were obtained from Bloomberg<sup>7</sup>. The data spans the period January 2000 to August 2021.

Stock returns are computed using the continuous compounding formula as:

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<sup>7</sup>All the data for this study were obtained from the Bloomberg terminal available at [Bloomberg Terminal | Bloomberg Professional Services](#)

$$y_t = 100 * \ln \left( \frac{P_t}{P_{t-1}} \right) \quad (1)$$

Where  $\ln$  is logarithm operator and  $y_t$  and  $P_t$  denote return and prices/share index, respectively. The computation of stock returns ensures that the series are stationary, ergodic, scale-free, and comparable (Bala & Takimoto, 2017; Liu, 2016); however, the study tests for unit root using the Augmented Dickey-Fuller technique with and without structural breaks and the return series are adjusted for structural breaks. After computing stock returns, we lost one data point due to differencing, hence, the study analysis is for 2000M02 to 2021M08. The study estimates variants of multivariate GARCH (MGARCH) models for pairs of markets (Nigeria and each of the global stock markets) using the return series adjusted for structural breaks.

### 3.2 Model Specification

We specify an m-dimensional conditional mean equation as

$$R_t = \Omega + \Lambda R_{t-1} + \varepsilon_t, \quad \varepsilon_t = H_t^{\frac{1}{2}} v_t, v_t \sim (0, 1), \varepsilon_t \sim (0, H_t) \quad (2)$$

Where:  $R_t$  is an  $n \times 1$  vector of stock returns at time  $t$ ,  $\Omega$  is a vector of constants,  $\Lambda$  is a matrix of coefficients on lagged stock returns of the form  $\begin{pmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{pmatrix}$ . It explains the spillover effect between Nigerian stock returns and each of the global markets:  $\varphi_{11}$  measures the effect of Nigeria's own stock return from previous period;  $\varphi_{12}$  is the effect of Nigeria's stock returns spillover to global stock markets;  $\varphi_{21}$  is global stock returns spillover to Nigeria; and  $\varphi_{22}$  is global own stock return spillover from previous period. For efficient stock markets, the own returns spillovers are expected to be statistically equal to zero in tandem with the efficient market hypothesis while the return spillover across markets are expected to be statistically different from zero if the markets are integrated.  $R_{t-1}$  is one period lagged vector of stock returns;  $\varepsilon_t$  is  $n \times 1$  vector of disturbances; and  $v_t$  denotes white noise error term.  $H_t$  is  $n \times n$  variance-covariance matrix.

Financial time series are known to exhibit asymmetries in their response to shock. That is, positive and negative shock do not always have similar impact on volatility. Therefore, the study models the variance following the diagonal BEKK asymmetry MGARCH (BEKK-AMGARCH(1, 1)) approach proposed by Kroner and Ng (1998) to capture the effects of asymmetric time-varying variance-covariance process as:

$$H_t = C'C + A' \varepsilon_{t-1} \varepsilon_{t-1}' A + D' \varepsilon_{t-1}^* \varepsilon_{t-1}^{*'} D + B' H_{t-i} B, \quad \varepsilon_t^* = \varepsilon_t I(\varepsilon_t < 0) \quad (3)$$

Where other variables remained as previously defined,  $C$  is an  $m \times m$  triangular matrix of constants; the elements of the diagonal matrices  $A$  and  $B$  capture the effect of shock on volatility (ARCH effect), and volatility persistence (GARCH effect), respectively;  $D$  is a diagonal parameter matrix which measures the response of volatility to negative shock ( $\varepsilon_{t-1}^*$ ) and  $I$  is an indicator variable that takes on unity whenever  $\varepsilon_t$  is negative and zero otherwise. Therefore, positive (negative) and statistically significant  $D$  indicates that negative shock has larger (smaller) effect on volatility.

For robustness, the study also estimates three variants of symmetric MGARCH model (diagonal VEC-MGARCH and BEKK-MGARCH, and the CCC-MGARCH).

## 4. Results and Discussion

### 4.1 Descriptive Statistics

Table 1 presents the descriptive statistics of stock returns in the six markets. The mean stock return is positive in all markets indicating average monthly gains in the stocks. The Nigerian stock market dominates as its expected monthly return (NG) is the largest during the study period followed by the United States (US), China (CH), and Hong Kong (HK). The United Kingdom (UK) has the least average monthly returns during the period followed by Japan (JP). The marked difference between the Nigerian stock return and those of the developed economies could be attributed to the global financial crisis which hit the world's most developed stock markets more severely. Another factor could be that the Nigerian market is less developed and leaves room for investors to consistently predict the direction of the market and make higher profits. The CH (3.2) and NG (3.03) have the highest volatility indicating that they suffered the largest fluctuations during the study period and were most risky, which explains why their expected returns were largest. The lowest standard deviation was observed in the UK, indicating that the market was less volatile and the least risky.

Table 1: Summary Statistics

	US	UK	JP	HK	CH	NG
Mean	0.19	0.02	0.06	0.13	0.13	0.32
Median	0.45	0.33	0.28	0.55	0.27	0.2
Maximum	5.19	5.06	6.09	7.17	10.59	14.33
Minimum	-8.06	-6.45	-11.82	-11.13	-12.26	-15.88
Std. Dev.	1.9	1.74	2.43	2.67	3.2	3.03
Skewness	-0.74	-0.71	-0.72	-0.7	-0.53	-0.45
Kurtosis	4.55	4.27	4.51	4.37	5.15	7.64
Observations	259	259	259	259	259	259

*Note: US is the US Standard and Poor 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns.*

All the stock returns are centered around zero with volatility clustering (Figure 1). This means that all the return series show volatility clustering with wild (calm) periods follow from wild (calm) periods; thus, the data generating process of the stock returns exhibits characteristics of heteroskedasticity. Most of the series exhibit wide swings during the global financial crisis between October 2008 and January 2009. Specifically, the US, CH, JP, and HK showed wide swings in October 2008 during the peak of the crisis whereas the NG showed high volatility between November 2008 and January 2009.

Table 2 reports the unconditional correlation coefficients of stock returns from the selected markets. The last row shows the correlation between NG and the other markets. The results are all positive and less than unity, indicating that assets in the Nigerian stock market can form a good portfolio with assets in any of the markets. However, including US, UK, JP, and HK in the same portfolio increases the risk. This may mean that the NG and CH are not as integrated as the other stock markets.

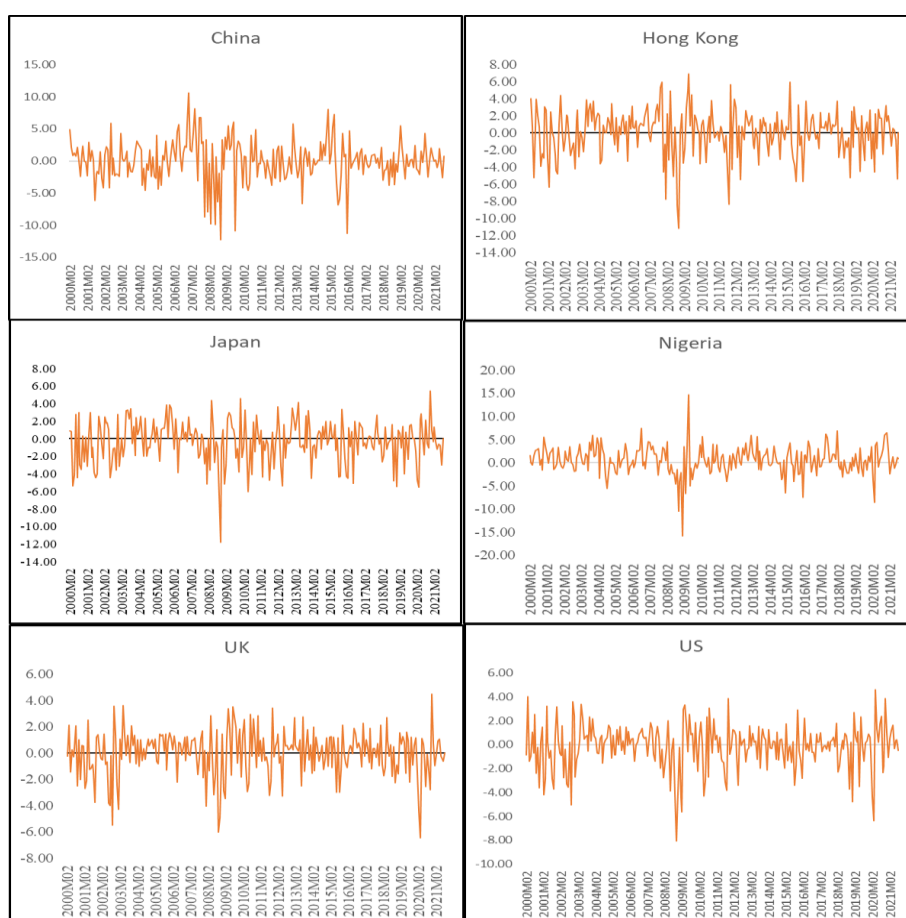


Figure 1: Stock returns

Table 2: Unconditional stock returns correlation

	US	UK	CH	JP	HK	NG
US	1.00					
UK	0.82	1.00				
CH	0.33	0.26	1.00			
JP	0.66	0.60	0.33	1.00		
HK	0.67	0.63	0.57	0.59	1.00	
NG	0.25	0.21	0.18	0.22	0.31	1.00

*Note: US is the US Standard and Poor 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns.*

## 4.2 Pre-Estimation Results

Table 3 presents the unit root test results for the return series with and without structural breaks. The results indicate that the series are all stationary at level. This is expected for returns series since their computational formula means that the series are the first differences of the respective stock prices. These results hold with and without accounting for structural breaks. All the stock returns (except UK) exhibit structural breaks during the global financial crisis between October 2008 and January 2009. Specifically, the US, CH, JP, and HK each shows structural break in October 2008 during the peak of the crisis while the NG shows structural break in January 2009, which is also attributable to the GFC. The UK structural break occurs in March 2020, after the declaration of Covid-19 as a pandemic.

Table 3: Stock returns unit root test results

Variable	Model Type (C, T)	Augmented Dickey-Fuller			Augmented Dickey-Fuller with Breaks		
		ADF-Stat	Included Lags	~I(d)	ADF-Stat	Break date	~I(d)
US	(1,0)	-14.801***	0	I(0)	-15.98348	2008M10	I(0)
UK	(1,0)	-15.900***	0	I(0)	-16.77832	2020M03	I(0)
CH	(1,0)	-5.932***	13	I(0)	-14.94875	2008M10	I(0)
JP	(1,0)	-14.142***	0	I(0)	-15.5296	2008M10	I(0)
HK	(1,0)	-14.259***	0	I(0)	-15.17498	2008M10	I(0)
NG	(1,0)	-5.755***	4	I(0)	-14.53765	2009M01	I(0)

*Note: US is the US Standard and Poor's 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns; C and T represent constant and Trend, respectively.*

Next, we examine the mean equations for serial correlation and heteroskedasticity using the Portmanteau residual tests and report the results in Table 6. The residuals from the mean

equations exhibit significant autocorrelation as indicated by the Ljung-Box Q statistics that are significant up to the lag order of 12. The adjusted Ljung-Box Q statistics show similar results suggesting the presence of significant heteroskedasticity.

Table 4: Residual Portmanteau Residual Tests

Statistics	NG /CH	NG/HK	NG/JP	NG/UK	NG /US
LB-Q(2)	5.456 (0.708)	6.131 (0.633)	13.115 (0.108)	7.462 (0.488)	14.844 (0.062)
LB-Q(6)	47.692 (0.003)	35.818 (0.057)	34.398 (0.078)	34.769 (0.072)	46.908 (0.003)
LB-Q(12)	84.546 (0.001)	68.086 (0.030)	58.504 (0.142)	59.918 (0.116)	72.033 (0.014)
LB-Adj Q(2)	5.498 (0.703)	6.169 (0.628)	13.174 (0.106)	7.498 (0.484)	14.927 (0.061)
LB-Adj Q(6)	48.399 (0.002)	36.343 (0.051)	34.797 (0.072)	35.231 (0.065)	47.532 (0.002)
LB-Adj Q (12)	86.765 (0.001)	69.825 (0.022)	59.819 (0.118)	61.306 (0.094)	73.522 (0.010)

*LB-Q(i) and LB-Adj Q(i) denote the Ljung-Box Q and adjusted Q statistics at lags  $i = 2, 6$  and  $12$ . The LB-Q(i) and LB-Adj Q(i) are used to test for the presence of autocorrelation and heteroskedasticity in the residuals, respectively. Values in parenthesis ( ) are p-values. NG, CH, HK, JP, UK and US denote the Nigerian, Chinese, Hong Kong, Japanese, the United Kingdom and the United States stock returns, respectively.*

### 4.3 Empirical Results

The study estimates the diagonal VEC-MGARCH (DVECH-MGARCH(1, 1), diagonal BEKK-MGARCH(1, 1), diagonal BEKK-AMGARCH(1, 1), and the CCC-MGARCH(1, 1) models for the return series, after adjusting for structural breaks. The statistical properties of the estimates are only marginally different, though, the model selection criteria indicates that the diagonal BEKK-AMGARCH(1, 1) performs better than the other competing models (Table 5).

Table 5: Competing models and selection criteria

Model	NG /CH	NG/HK	NG/JP	NG/UK	NG /US
Log likelihood					
DVECH-MGARCH	-1269.080	-1226.560	-1209.420	-1121.030	-1132.100
DBEKK-MGARCH	-1266.670	-1223.960	-1207.220	-1118.780	-1128.650
CCC-MGARCH	-1260.300	-1214.530	-1219.930	-1114.000	-1123.250
DBEKK-AMGARCH	-1255.470	-1206.390	-1198.400	-1104.360	-1111.080
Akaike information criteria					
DVECH-MGARCH	9.931	9.601	9.468	8.783	8.869
DBEKK-MGARCH	9.920	9.590	9.460	8.770	8.850
CCC-MGARCH	9.870	9.530	9.560	8.740	8.810
DBEKK-AMGARCH	9.850	9.450	9.410	8.680	8.730
Schwartz information criteria					
DVECH-MGARCH	10.096	9.766	9.634	9.610	9.034
DBEKK-MGARCH	10.100	9.770	9.640	8.950	9.030

CCC-MGARCH	10.060	9.740	9.740	8.948	8.990
DBEKK-AMGARCH	10.050	9.630	9.610	8.920	8.880

Note: NG, CH, HK, JP, UK, and US denote Nigeria, China, Hong Kong, Japan, United Kingdom, and the United States stock market return, respectively. DVECH, DBEKK, CCC, MGARCH, and AMGARCH denote diagonal vech, Baba-Engel-Kraft-Kroner, constant conditional correlation, and asymmetric multivariate generalized autoregressive conditional heteroskedasticity models, respectively. When comparing models, the better model is the one with the largest loglikelihood or the least Akaike or Schwartz information criteria.

Table 6 presents the results for the diagonal BEKK-AMGARCH model (results for the other models are in the appendix). The results are in two segments: the first is the mean equation representing return spillover effects; and the second is the variance equation from where the own and cross volatility transmission are derived and presented in equations 4 to 18.

Table 6: Returns, shock and volatility spillover from BEKK-AMGARCH

	NG/CH	NG/HK	NG/JP	NG/UK	NG/US
Mean Equation					
$\mu_{11}$	0.47** (0.197)	0.54*** (0.197)	0.56*** (0.199)	0.52** (0.205)	0.51** (0.212)
$\varphi_{11}$	0.21*** (0.070)	0.19*** (0.068)	0.16** (0.070)	0.17** (0.072)	0.18*** (0.070)
$\varphi_{12}$	-0.01 (0.055)	0.02 (0.064)	0.17** (0.071)	0.10 (0.081)	0.10 (0.097)
$\mu_{22}$	-0.10 (0.169)	0.05 (0.172)	-0.26* (0.156)	0.10 (0.111)	-0.12 (0.118)
$\varphi_{21}$	0.06 (0.072)	0.10 (0.079)	0.04 (0.050)	-0.07 (0.069)	0.02 (0.076)
$\varphi_{22}$	0.01 (0.066)	0.10 (0.058)	0.11 (0.072)	-0.03 (0.034)	-7.66E-05 (0.035)
Variance Equation					
$s_{11}$	1.25** (0.540)	1.11** (0.492)	1.21** (0.597)	1.35** (0.664)	1.22** (0.602)
$s_{12}$	0.31* (0.169)	0.36** (0.161)	0.13 (0.157)	0.10 (0.091)	0.16* (0.093)
$s_{22}$	0.56 (0.347)	0.98** (0.485)	0.95 (0.750)	0.40* (0.217)	0.30** (0.138)
$\alpha_{11}$	0.07 (0.187)	0.05 (0.150)	-0.11 (0.239)	0.19 (0.188)	-0.19 (0.171)
$\alpha_{22}$	0.42*** (0.074)	0.36*** (0.080)	0.16 (0.239)	-0.20 (0.221)	0.14 (0.204)
$d_{11}$	0.49*** (0.083)	0.47*** (0.077)	0.48*** (0.10)	0.46*** (0.106)	0.45*** (0.106)
$d_{22}$	0.04 (0.169)	0.13 (0.169)	0.30*** (0.104)	0.51*** (0.115)	0.52*** (0.093)
$\beta_{11}$	0.85*** (0.057)	0.88*** (0.053)	0.85*** (0.068)	0.83*** (0.077)	0.85*** (0.067)
$\beta_{22}$	0.88*** (0.046)	0.84*** (0.066)	0.86*** (0.096)	0.82*** (0.080)	0.85*** (0.045)

Note: US is the US Standard and Poors 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns;  $\mu_{ij}$ s are elements of the diagonal matrix  $\Omega$ , they denote the conditional stock return from market j to market i;  $\varphi_{ij}$ s are elements of the matrix  $\Lambda$  and denote return spillover effect from market j to market i;  $s_{ij}$ s are elements of the triangular matrix  $C$  in equation (3) and are used to determine the level of risk associated with return in each market for  $i = j$ , risk spillover for  $i \neq j$ ;  $\alpha_{ij}$ s,  $\beta_{ij}$ s, and  $d_{ij}$ s are elements of the diagonal matrices  $A$ ,  $D$ , and  $B$ , respectively. They denote the ARCH (shock), GARCH (volatility persistence), and asymmetric ARCH effects, respectively; using the parameters from the variance equation, volatility spillovers for each pair of markets is given as  $h_{11} = s_{11} + \alpha_{11}^2 \varepsilon_{1,t-1}^2 + d_{11}^2 \varepsilon_{1,t-1}^2 \varepsilon_{1,t-1}^* + \beta_{11}^2 h_{11,t-1}$  and  $h_{22} = s_{22} + \alpha_{22}^2 \varepsilon_{2,t-1}^2 + d_{22}^2 \varepsilon_{2,t-1}^2 \varepsilon_{2,t-1}^* + \beta_{22}^2 h_{22,t-1}$  for own market volatility generated from markets 1 and 2, respectively, and  $h_{12} = s_{12} + \alpha_{11} \alpha_{22} \varepsilon_{1,t-1} \varepsilon_{2,t-1} + d_{11} d_{22} \varepsilon_{1,t-1} \varepsilon_{2,t-1}^* \varepsilon_{2,t-1}^* + \beta_{11} \beta_{22} h_{12,t-1}$  for cross-market volatility spillover. Values in parenthesis ( ) are standard errors.

Nigeria and China

$$h_{11} = 1.25 + 0.005\varepsilon_{1,t-1}^2 + 0.24\varepsilon_{1,t-1}^2 \varepsilon_{1,t-1}^* + 0.73h_{1,t-1} \quad (4)$$

$$h_{22} = 0.56 + 0.18\varepsilon_{2,t-1}^2 + 0.001\varepsilon_{2,t-1}^2 \varepsilon_{2,t-1}^* + 0.77h_{2,t-1} \quad (5)$$

$$h_{12} = 0.31 - 0.03\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.02\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^* + 0.75h_{12,t-1} \quad (6)$$

Nigeria and Hong Kong

$$h_{11} = 1.11 + 0.002\varepsilon_{1,t-1}^2 + 0.23\varepsilon_{1,t-1}^2\varepsilon_{1,t-1}^* + 0.75h_{1,t-1} \quad (7)$$

$$h_{22} = 0.98 + 0.13\varepsilon_{2,t-1}^2 + 0.02\varepsilon_{2,t-1}^2\varepsilon_{2,t-1}^* + 0.71h_{2,t-1} \quad (8)$$

$$h_{12} = 0.36 - 0.02\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.06\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^* + 0.73h_{12,t-1} \quad (9)$$

Nigeria and Japan

$$h_{11} = 1.21 + 0.01\varepsilon_{1,t-1}^2 + 0.23\varepsilon_{1,t-1}^2\varepsilon_{1,t-1}^* + 0.72h_{1,t-1} \quad (10)$$

$$h_{22} = 0.95 + 0.02\varepsilon_{2,t-1}^2 + 0.09\varepsilon_{2,t-1}^2\varepsilon_{2,t-1}^* + 0.75h_{2,t-1} \quad (11)$$

$$h_{12} = 0.13 - 0.02\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.15\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^* + 0.73h_{12,t-1} \quad (12)$$

Nigeria and UK

$$h_{11} = 1.35 + 0.04\varepsilon_{1,t-1}^2 + 0.22\varepsilon_{1,t-1}^2\varepsilon_{1,t-1}^* + 0.70h_{1,t-1} \quad (13)$$

$$h_{22} = 0.40 + 0.04\varepsilon_{2,t-1}^2 + 0.26\varepsilon_{2,t-1}^2\varepsilon_{2,t-1}^* + 0.67h_{2,t-1} \quad (14)$$

$$h_{12} = 0.10 - 0.04\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.24\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^* + 0.68h_{12,t-1} \quad (15)$$

Nigeria and US

$$h_{11} = 1.22 + 0.04\varepsilon_{1,t-1}^2 + 0.20\varepsilon_{1,t-1}^2\varepsilon_{1,t-1}^* + 0.72h_{1,t-1} \quad (16)$$

$$h_{22} = 0.30 + 0.02\varepsilon_{2,t-1}^2 + 0.19\varepsilon_{2,t-1}^2\varepsilon_{2,t-1}^* + 0.73h_{2,t-1} \quad (17)$$

$$h_{12} = 0.16 - 0.03\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 0.23\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^* + 0.72h_{12,t-1} \quad (18)$$

#### 4.3.1 Return spillover

Results for the mean equation presented in Table 5 represent returns spillover from Nigerian stock market to global stock markets and vice versa, and from previous period own return. The spillover effect of own return ( $\varphi_{11}$ ) is positive for Nigeria and statistically significant at least at the conventional 5% level. These results indicate that investors can consistently predict returns in Nigeria, which is a usual feature of less developed markets suggesting that the Nigeria stock market is less developed. Less developed markets are usually narrow and shallow; information on stock prices may be widely available, but not simultaneously to all players in the market; hence, there is information asymmetry, which enable investors to beat the market to higher returns than the market average. In addition, the results mean that the Nigerian stock market is not integrated to the rest of the markets since own return spillover is higher than spillover from other markets.

The effect of own return spillover ( $\varphi_{22}$ ) is negative for the US and UK but positive for CH, JP, and HK; however, they are all statistically not significant at the conventional 5% level. These results are characteristic of developed financial markets and are consistent with the efficient market hypothesis; hence, these markets can be said to be efficient. These markets are wide and deep, and information concerning stock prices is widely available to buyers and sellers simultaneously. Therefore, investors are not able to consistently predict returns in these markets, and so could not make higher profit than the market average.

Returns spillover effect to NG ( $\varphi_{12}$ ) from the global stock markets are positive except for CH. This means that the way NG responds to positive returns in each of the global markets is similar, except for CH where NG responds negatively to a positive change in return. It turns out that only JP is statistically significant, indicating that return spillover from Japan generates a positive response in Nigeria, hence, positive return in the Japanese stock market increases returns in Nigeria. However, there is no return spillover from Nigeria to the other markets as all the coefficients ( $\varphi_{21}$ ) are positive but statistically not significant except for UK that was negative, though, statistically not significant as well. These results suggests that the Nigerian and Japanese markets provide opportunity for portfolio diversification, which investors could explore. They also support the strand of literature which argues that return spillover move from developed to developing markets (Obadiaru *et al.*, 2020; Obadiaru *et al.*, 2018; Phume & Bonga-Bonga, 2018).

#### **4.3.2 Shock and Volatility Spillover**

The second segment of results in Table 5 represents shock and volatility transmission/spillover from own and across returns. The scalars generated from the variance equations are presented in equations 4 to 18. First, we compare the constants of the conditional variances of the NG with each of the global stock returns considered. These constants denote the level of risk the individual markets face such that the higher the value the higher the risk facing the associated market. In all the pair of markets,  $h_{11}$  has the highest constant of at least 1.11 suggesting that investors face higher risk investing in the Nigerian market compared to the other markets during the period. This is intuitively plausible, as less developed markets face higher risk due to market imperfections. Closely following NG are JP and HK, which show similar risk level of 0.95 and 0.98, respectively, suggesting that when new information emanates, it is quickly shared among investors in these markets. Investors in the US market face the lowest risk as the conditional variance of the US showed the least constant.

Next, we consider the ARCH effect, which measures the impact of previous information shock (innovation) on market risk (volatility). The results show that all the returns we compared the NG with, CH has the largest ARCH effect (the coefficient on  $\varepsilon_{2,t-1}^2$  in equation (5) is 0.18), indicating that volatility in the Chinese stock market has the highest level of sensitivity to past market innovations compared to other stock markets. This suggests that shock arising from within the Chinese market heightens market risk in the country more, compared to other countries, meaning that domestic events shape the Chinese market more. This is intuitively plausible as the market arguably faces extensive capital control/financial repression, which are either not present or minimal in other markets. The least sensitive to previous market information shock is JP, suggesting that domestic events have the least impact on market risk in Japan. This means that, if each of the markets face a domestic shock of equal magnitude, the Japanese market will be the least affected. Results on asymmetry indicate that, except CH and HK, volatility in each of the stock returns are relatively more sensitive to negative information shock compared to positive innovations, suggesting that bad news heightens market risk more in these countries and the UK is more sensitive to negative information shock compared to all the other markets. This indicates that investors react more to negative news leading to heightened speculative activities and, consequently, trading activities.

Regarding volatility spillover ( $h_{12}$ ), all the coefficients on the common information shock ( $\varepsilon_{1,t-1}\varepsilon_{2,t-1}$ ) show negative sign, suggesting that volatility spillover between NG and each of the global stock markets is declining on positive information shock. This response is relatively faster between the NG and the UK, suggesting that positive news shared between UK and NG have the strongest impact on reducing future volatility spillover. However, all the coefficients on the asymmetric term ( $\varepsilon_{1,t-1}\varepsilon_{1,t-1}^*\varepsilon_{2,t-1}\varepsilon_{2,t-1}^*$ ) show positive sign, indicating that bad news has more impact on volatility spillovers compared to good news as expected, and the impact of volatility spillover is largest between the UK and NG. This indicates that more trading activities take place between Nigeria and the UK, and that information asymmetry plays an important role in shaping the shared risk between the two markets. This is not surprising as there is a subsisting MoU between Nigeria, and the London stock exchanges to double-list firms in the two markets to foster financial integration between the countries, thus increasing trading activities between the markets. This finding is in line with the strand of the literature suggesting that good and bad news do not have the same impact on volatility spillover (Panda & Thiripalraju, 2018; Majdoub & Sassi, 2017). On GARCH effect, volatility persistence between NG and each of the stock returns results indicate larger persistence between NG and

CH, though, the value is marginally greater than those between NG and each of the other markets. This suggests that when there is a shock that affects Nigeria and each of the markets, the tendency is that it will take a longer time for the impact on volatility between Nigeria and China to fizzle out compared to the other markets. This is intuitively plausible since the two markets are less developed and have more imperfections compared to others. Generally, the cross-market volatility persistence is less than the individual market volatility persistence, suggesting that the impact of a shock on market risk dissipates faster for shared risk than own market risk. This indicates that financial integration is important in reducing the risk associated with each market.

### 4.3.3 Diagnostics

Table 7 presents the diagnostic test results. The system residual Portmanteau Ljung-Box Q-statistics indicate the absence of multivariate autocorrelation up to lag order of 12 since the test fails to reject the null hypothesis of no autocorrelation. The test results also show the absence of further heteroskedasticity as the Ljung-Box Adjusted Q-statistics could not reject the null hypothesis of no heteroskedasticity. The absence of multivariate serial correlation and heteroskedasticity implies that our models are adequate in capturing the volatility in the series.

Table 7: Residual Portmanteau Residual Tests

Statistics	NG /CH	NG/HK	NG/JP	NG/UK	NG /US
LB-Q(2)	4.201 (0.839)	2.904 (0.940)	2.445 (0.964)	3.478 (0.901)	3.989 (0.858)
LB-Q(6)	25.589 (0.374)	20.696 (0.657)	24.456 (0.436)	18.099 (0.798)	22.549 (0.547)
LB-Q(12)	54.093 (0.253)	45.646 (0.570)	50.406 (0.379)	39.297 (0.810)	47.793 (0.481)
LB-Adj Q(2)	4.2295 (0.836)	2.933 (0.939)	2.459 (0.964)	3.498 (0.899)	4.014 (0.856)
LB-Adj Q(6)	25.975 (0.354)	21.024 (0.637)	24.830 (0.415)	18.355 (0.786)	22.896 (0.526)
LB-Adj Q (12)	55.604 (0.210)	46.900 (0.518)	51.780 (0.329)	40.330 (0.776)	49.010 (0.432)

*LB-Q(i) and LB-Adj Q(i) denote the Ljung-Box Q and adjusted Q statistics at lags i = 2, 6 and 12. The LB-Q(i) and LB-Adj Q(i) are used to test for the presence of autocorrelation and heteroskedasticity in the residuals, respectively. Values in parenthesis ( ) are p-values. NG, CH, HK, JP, UK and US denote the Nigerian, Chinese, Hong Kong, Japanese, the United Kingdom and the United States stock returns, respectively.*

## 5. Conclusion and Policy Implications

Return and volatility spillover among financial assets/markets is important for portfolio diversification and could have significant influence on economic policy formulation. Therefore, understanding the sources of return and volatility spillover to domestic markets is

significant to investors and policy makers in their efforts to diversify investment portfolio and formulate macroeconomic policy, respectively. The level of financial integration has been identified as one important source of return and volatility spillover among financial markets. This study examines return and volatility spillover between Nigeria and five selected stock markets in the world using a diagonal BEKK-AMGARCH model.

Findings reveal that markets with higher volatility show the largest returns suggesting that on an individual basis, markets with higher risk are more beneficial for investors. The Nigerian stock market displays the characteristics of less developed and inefficient market, as previous return spillovers to the current, making the market predictable thus, investors could consistently make higher profit than the market average. The other selected markets did not exhibit this feature, thus placing them as more developed markets. Return transmission between markets was observed only between Japan and Nigeria suggesting that investors can make higher returns by combining assets from these markets to form a portfolio rather than choosing one of the two.

The study also infers that domestic events are more important for the evolution of risk in China, as volatility in the Chinese market is relatively more sensitive to past own shock. This explains the role that capital control/financial repression plays in China by insulating the country from external shocks. Volatility in the Japanese market appears to be less influenced by domestic shocks, suggesting that the market could be more susceptible to external shocks. Except CH and HK, all the return volatilities are relatively more sensitive to bad news compared to good news, indicating that negative information shock heightens market risk, and this is more prominent in the UK. This suggests that negative information increases speculation, hence, trading activities increase and raises the level of risk.

On volatility spillover, the study reveals that Nigeria interacts more with China compared to the other markets as the cross-market volatility persistence is largest between the two markets. This indicates that the effect of a shock that heightens cross-market risk between the two markets only dies out after a long period. Positive information shared between Nigeria and the UK reduces cross-market risk between the two markets whereas negative news heightens it, suggesting that trading activities thrive more on negative news since it increases speculation. The study further submits that the impact of a shock on cross-market volatility takes a longer time to fizzle out compared to the impact of the same shock on own market volatility in all cases. Finally, volatility spillover between Nigeria and each of the markets appear to be

declining, indicating reducing level of market activities between Nigeria and each of the market.

The implications of the findings are manifold. First, Nigerian stock return is dominated by own return spillover, though, investors can hedge against loss in Japan by taking advantage of the large returns derivable from Nigeria if their diversification strategy includes assets from the two markets since the Nigerian stock return responds positively to positive changes in Japanese returns. Thus, investors should include assets in the Nigeria stock exchange and Japan in their portfolios to take advantage of the diversification opportunity they present. Second, due to higher volatility persistence between Nigeria and China the monetary authorities in Nigeria should keep a watchful eye on shocks/adverse events emanating from China with a view to preventing or minimizing the effects of the spillover of such events on market risk in Nigeria.

Third, the Nigerian stock market is less developed and less integrated to the others. To increase market activities and foster integration to other markets, there is the need to improve the trading infrastructure/institution and have memorandums of understanding (MoUs) with other markets to allow for cross-listings of firms in the Nigeria market on other exchanges.

Examining the effects of global crises such as the global financial crisis and the covid-19 on return and volatility spillover will be valuable addition to the literature, however, we have reserved this area for future research.

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## APPENDIX: Additional Results

Table A1: Stock returns and volatility spillover from diagonal VECH MGARCH

	NG/CH	NG/HK	NG/JP	NG/UK	NG/US
Mean Equation					
$\mu_1$	-0.06 (0.167)	0.027 (0.165)	-0.268* (0.157)	0.083 (0.115)	-0.075 (0.125)
$\mu_2$	0.619*** (0.182)	0.656*** (0.187)	0.699*** (0.195)	0.620*** (0.196)	0.596*** (0.202)
$\varphi_{11}$	0.095 (0.063)	0.1 (0.070)	0.103 (0.067)	-0.005 (0.063)	0.011 (0.070)
$\varphi_{12}$	0.022 (0.064)	0.07 (0.056)	0.055 (0.049)	-0.006 (0.033)	0.02 (0.030)
$\varphi_{21}$	-0.041 (0.049)	0.007 (0.057)	0.176** (0.070)	0.115 (0.074)	0.124 (0.097)
$\varphi_{22}$	0.178*** (0.066)	0.186*** (0.069)	0.165** (0.070)	0.179*** (0.067)	0.178*** (0.068)
Variance Equation					
$s_{11}$	0.493* (0.267)	0.841* (0.478)	0.926 (1.002)	0.269 (0.178)	0.216** (0.109)
$s_{22}$	1.289** (0.062)	1.010** (0.506)	1.202* (0.615)	1.195** (0.571)	1.599** (0.623)
$\alpha_{11}$	0.145*** (0.051)	0.108** (0.046)	0.047* (0.029)	0.134*** (0.046)	0.163*** (0.042)
$\alpha_{21}$	0.155*** (0.041)	0.130*** (0.033)	0.086*** (0.025)	0.139*** (0.028)	0.158*** (0.031)
$\alpha_{22}$	0.165*** (0.055)	0.156*** (0.049)	0.157** (0.063)	0.145** (0.059)	0.153** (0.060)
$\beta_{11}$	0.813*** (0.061)	0.761*** (0.107)	0.780*** (0.201)	0.777*** (0.087)	0.775*** (0.052)
$\beta_{21}$	0.750*** (0.059)	0.747*** (0.065)	0.740*** (0.097)	0.749*** (0.052)	0.719*** (0.060)
$\beta_{22}$	0.699*** (0.105)	0.733*** (0.095)	0.702*** (0.117)	0.723*** (0.107)	0.667*** (0.107)

Note: US is the US Standard and Poors 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns;  $\mu_{ij}$ s are elements of the diagonal matrix  $\Omega$  they denote the conditional stock return from market j to market i;  $\varphi_{ij}$ s are elements of the matrix  $\Lambda$  and denote return spillover effect from market j to market i;  $s_{ij}$ s are elements of the triangular matrix  $C$  in equation (3) and are used to determine the level of risk associated with return in each market for  $i = j$ , risk spillover for  $i \neq j$ ;  $\alpha'_{ij}$ s and  $\beta'_{ij}$ s are elements of the triangular matrices  $A$  and  $B$ , respectively. They denote the ARCH (shock) and GARCH (volatility persistence) effects, respectively; using the parameters from the variance equation, volatility spillovers for each pair of markets is given as  $h_{11} = s_{11} + \alpha_{11}^2 \varepsilon_{1,t-1}^2 + \beta_{11}^2 h_{11,t-1}$  and  $h_{22} = s_{22} + \alpha_{22}^2 \varepsilon_{2,t-1}^2 + \beta_{22}^2 h_{22,t-1}$  for own market volatility generated from markets 1 and 2 respectively, and  $h_{21} = s_{21} + \alpha_{21} \varepsilon_{1,t-1} \varepsilon_{2,t-1} + \beta_{21} h_{12,t-1}$  for cross-market volatility spillover. Values in parenthesis ( ) are standard errors; and \*\*\*(\*\*)\* indicate statistical significance at 1%(5%)10% levels, respectively.

Table A2: Stock returns and volatility spillovers from diagonal BEKK-MGARCH

	NG/CH	NG/HK	NG/JP	NG/UK	NG/US
Mean Equation					
$\mu_{10}$	0.63*** (0.185)	0.66*** (0.190)	0.69*** (0.197)	0.63*** (0.199)	0.58*** (0.207)
$\mu_{11}$	0.17** (0.069)	0.18*** (0.069)	0.174** (0.071)	0.18** (0.071)	0.19*** (0.071)
$\mu_{12}$	-0.04 (0.050)	0.01 (0.058)	0.17** (0.073)	0.1 (0.075)	0.12 (0.101)
$\varphi_{20}$	-0.06 (0.174)	0.019 (0.174)	-0.27* (0.170)	0.09 (0.115)	-0.09 (0.085)
$\varphi_{22}$	<b>0.09</b> <b>(0.064)</b>	<b>0.1</b> <b>(0.070)</b>	<b>0.09</b> <b>(0.067)</b>	<b>-0.06</b> <b>(0.069)</b>	<b>-0.002</b> <b>(0.072)</b>
$\varphi_{21}$	0.02 (0.066)	0.07 (0.054)	0.06 (0.050)	-0.01 (0.032)	0.02 (0.031)
Variance Equation					
$s_{11}$	1.50** (0.725)	1.09* (0.584)	1.26* (0.694)	1.33* (0.682)	1.86** (0.737)
$s_{12}$	0.26 (0.176)	0.24* (0.129)	0.21 (0.155)	0.14* (0.081)	0.21** (0.091)
$s_{22}$	0.50* (0.127)	1.00* (0.541)	0.93 (1.234)	0.3 (0.191)	0.22** (0.111)
$\alpha_{11}$	0.42*** (0.069)	0.38*** (0.068)	0.39*** (0.084)	0.38*** (0.082)	0.38*** (0.080)
$\alpha_{22}$	0.36*** (0.069)	0.32*** (0.073)	0.17** (0.071)	0.37*** (0.065)	0.42*** (0.057)
$\beta_{11}$	0.82*** (0.075)	0.86*** (0.064)	0.84*** (0.078)	0.84*** (0.073)	0.80*** (0.073)
$\beta_{22}$	0.91*** (0.033)	0.86*** (0.067)	0.89*** (0.134)	0.87*** (0.052)	0.87*** (0.031)

Note: US is the US Standard and Poors 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns;  $\mu_{ij}$ s are elements of the diagonal matrix  $\Omega$  they denote the conditional stock return from market j to market i;  $\varphi_{ij}$ s are elements of the matrix  $\Lambda$  and denote return spillover effect from market j to market i;  $s'_{ij}$ s are elements of the triangular matrix  $C$  in equation (3) and are used to determine the level of risk associated with return in each market for  $i = j$ , risk spillover for  $i \neq j$ ;  $\alpha'_{ij}$ s,  $\beta'_{ij}$ s and  $d'_{ij}$ s are elements of the diagonal matrices  $A$ ,  $D$  and  $B$ , respectively. They denote the ARCH (shock), GARCH (volatility persistence) and asymmetric ARCH effects, respectively; using the parameters from the variance equation, volatility spillovers for each pair of markets is given as  $h_{11} = s_{11} + \alpha_{11}^2 \varepsilon_{1,t-1}^2 + \beta_{11}^2 h_{11,t-1}$  and  $h_{22} = s_{22} + \alpha_{22}^2 \varepsilon_{2,t-1}^2 + \beta_{22}^2 h_{22,t-1}$  for own market volatility generated from markets 1 and 2 respectively, and  $h_{12} = s_{12} + \alpha_{11} \alpha_{22} \varepsilon_{1,t-1} \varepsilon_{2,t-1} + \beta_{11} \beta_{22} h_{12,t-1}$  for cross-market volatility spillover. Values in parenthesis ( ) are standard errors; and \*\*\*(\*\*)\* indicate statistical significance at 1%(5%)10% levels, respectively.

Table A3: Stock returns and volatility spillovers from CCC-MGARCH

	NG/CH	NG/HK	NG/JP	NG/UK	NG/US
Mean Equation					
$\mu_{10}$	0.57*** (0.187)	0.67*** (0.194)	0.63*** (0.195)	0.65*** (0.197)	0.65*** (0.204)
$\mu_{11}$	0.21*** (0.074)	0.18** (0.073)	0.19*** (0.072)	0.19** (0.075)	0.19** (0.073)
$\mu_{12}$	-0.04 (0.166)	0.17** (0.071)	0.02 (0.057)	0.09 (0.082)	0.1 (0.094)
$\varphi_{20}$	-0.07 (0.166)	-0.25 (0.163)	0.1 (0.174)	0.16 (0.113)	-0.04 (0.121)
$\varphi_{22}$	<b>0.06</b> <b>(0.072)</b>	<b>0.09</b> <b>(0.073)</b>	<b>0.09</b> <b>(0.078)</b>	<b>-0.11</b> <b>(0.072)</b>	<b>-0.02</b> <b>(0.077)</b>
$\varphi_{21}$	0.004 (0.064)	0.05 (0.051)	0.05 (0.058)	-0.01 (0.034)	0.01 (0.034)
Variance Equation					
$s_{11}$	1.12* (0.059)	1.14* (0.693)	1.10* (0.634)	1.13 (0.693)	1.12* (0.680)
$\alpha_{11}$	0.16*** (0.062)	0.14** (0.064)	0.14** (0.060)	0.15** (0.070)	0.14** (0.066)
$\beta_{11}$	0.71*** (0.117)	0.72*** (0.133)	0.73*** (0.124)	0.72*** (0.137)	0.72*** (0.133)
$s_{22}$	0.54* (0.322)	0.92 (0.864)	0.97* (0.498)	0.39 (0.245)	0.25* (0.139)
$\alpha_{22}$	0.18*** (0.064)	0.09 (0.053)	0.14** (0.058)	0.23*** (0.087)	0.22*** (0.064)
$\beta_{22}$	0.77*** (0.077)	0.74*** (0.184)	0.71*** (0.115)	0.65*** (0.138)	0.71*** (0.076)
$R_{12}$	0.20*** (0.063)	0.19*** (0.006)	0.28*** (0.060)	0.20*** (0.065)	0.26*** (0.062)

Note: US is the US Standard and Poors 500 stock returns; UK is the UK Financial Times Stock Exchange returns; JP is Japanese Nikkei stock returns; HK is Hong Kong Heng Seng stock returns; CH is Chinese Shanghai stock returns; and NG is the Nigerian stock exchange returns;  $\mu'_{ij}$ s are elements of the triangular matrix  $\Omega$  they denote the conditional stock return from market j to market i;  $\varphi'_{ij}$ s are elements of the matrix  $\Lambda$  and denote return spillover effect from market j to market i;  $s'_{ij}$ s are elements of a diagonal matrix  $C$  and are used to determine the level of risk associated with return in each market for  $i = j$ , risk spillover for  $i \neq j$ ;  $\alpha'_{ij}$ s, and  $\beta'_{ij}$ s are elements of the diagonal matrices  $A$  and  $B$ , respectively. They denote the ARCH (shock), and GARCH (volatility persistence) effects, respectively;  $R$  is cross-correlation of volatility representing volatility spillover between the pairs of markets; using the parameters from the variance equation, volatility spillovers for each pair of markets is given as  $h_{11} = s_{11} + \alpha_{11}\varepsilon_{1,t-1}^2 + \beta_{11}h_{11,t-1}$  and  $h_{22} = s_{22} + \alpha_{22}\varepsilon_{2,t-1}^2 + \beta_{22}h_{22,t-1}$  for own market volatility generated from markets 1 and 2 respectively, and  $h_{12} = R_{12}\sqrt{h_{1,t-1}h_{2,t-1}}$  for cross-market volatility spillover. Values in parenthesis ( ) are standard errors; and \*\*\*(\*\*)\* indicate statistical significance at 1%(5%)10% levels, respectively.