DYNAMIC INTERDEPENDENCE BETWEEN CRUDE OIL PRICES AND FOREIGN EXCHANGE MARKET IN NIGERIA

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Abstract

Modelling volatility interdependence between crude oil and foreign exchange markets returns provides useful insights into how information is transmitted from the crude oil market to the foreign exchange market and vice versa. This paper evaluates dynamic interdependence between crude oil and foreign exchange markets by applying Baba, Engle, Kraft and Kroner (1990) (BEKK) specifications to crude oil prices and Naira/USD exchange rates. Estimates from the BEKK-GARCH (1,1) model indicate evidence of unidirectional shock and volatility transmission from crude oil market to foreign exchange market in Nigeria. Evidence of unidirectional volatility transmission provides support for partial interdependence between the markets in Nigeria. This finding has important implications for financial risk management, foreign exchange market regulation and crude oil revenue management policy.

1 Introduction

Studies of interdependence provide useful insight into how information is transmitted between markets. The need to establish the nature of interdependence between markets arises in response to growing integration of global markets resulting from liberalisation, advancement in information and communication technology (ICT), and the introduction of innovative financial products (Phylaktis & Ravazzolo, 2005; Panda, Nanda & Paital, 2019). The extent and direction of shock and volatility interdependence between two markets, for example, may help investors and

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regulators to forecast market movements. More so, absence of interdependence between the markets would enhance portfolio diversification opportunities between them. Hence, studies of markets interdependence are not only important for determining the extent of the markets' integration but also provides basis for portfolio diversification purposes and market regulation. These important applications together with evolution in financial econometric methodologies have given rise to numerous empirical research studies on the nature of interdependence between markets, even sectors of the same market. While some of the studies focused on return interdependence between international financial markets (see for example, Ozturk, Feridun & Kalyoncu, 2008; Brahmasrene, Huang & Sissoko, 2014); several others concentrated on return and volatility interdependence between the crude oil and financial markets (see for example, Malik & Ewing, 2009; Cifarelli & Paladino, 2010; Arouri, Jouini & Nguyen, 2011). While most of these studies were conducted for developed and emerging economies, the few studies using Africa data were conducted for Uganda and South Africa (see for example, Kin & Courage, 2014; Katusiime, 2019). Again, current studies using Nigeria data were either based on first moment or focused on other segments of the financial markets (see for example, Onoja, 2015; Fowowe, 2017).

Crude oil provides powerful propulsion for productivity in modern economies, but its pricing and distribution are highly centralized. As a consequence, the vast majority of crude oil trading occur through foreign trade, priced in US dollar. Given Nigeria's status as a major global crude oil producer, understanding the nature of volatility interdependence between crude oil price and foreign exchange rate in Nigeria is important for several reasons. First, the crude oil market is one of the most important markets in Nigeria as well as in the world economy due to the crucial role of oil within economic activity. Second, crude oil is the mainstay of the Nigerian economy and plays a vital role in shaping the economic and political destiny of the country. CBN (2012) reports, for example, that crude oil revenue accounted for 75,3% of federally collected revenue and crude oil exports accounted for 96,8% of total exports. This implies that 97% of export earnings are partially outside the control of Nigeria. Emenike (2015) observes that the developments in the international oil market have intensified the risks and vulnerabilities faced by oil exporting countries in the wake of a new episode of falling oil prices. Third, crude oil is priced primarily in US dollars; accordingly a change in crude oil prices may directly affect Naira exchange rates in terms of US Dollars. Changes in crude oil prices lead to changes in production costs in industries, thus affecting the prices of the related stocks. Also, consumption and investment levels in the economy varies according to changes in the crude oil prices, resulting in increase or decrease in overall reserves of deposit money banks. Finally, volatility in financial markets is believed to create financial flows to commodity markets, thus leading to commodity price changes (Brown & Yucel, 2002; Kilian, 2008). Evidence on the nature relationship between crude oil price and exchange rate is apt for Nigeria.

The objective of this study is to evaluate volatility interdependence between crude oil prices and foreign exchange market in Nigeria. The findings of this study will be of importance to existing and prospective foreign investors in Nigeria, foreign exchange market regulators and scholars. If there is evidence of interdependence between the markets, for example, foreign investors can minimize their foreign exchange risk by adjusting their portfolios in response to changes in crude oil prices. It will also enhance foreign exchange policy as regulators of the foreign exchange market can formulate proactive policies in response to anticipated changes in the crude oil prices. It will further enrich existing knowledge on interaction between crude oil and foreign exchange markets in development as well as provide literature for future researchers of related subject. The remainder of this paper organised as follows: Section 2 contains empirical literature review. Section 3 describes methodology and data for analysis. Section 4 presents empirical results ad discussions, and section 5 provides conclusions.

2 Empirical literature review

There is a sizable energy and financial economics literature on the nature of interdependence between crude oil price and foreign exchange rate because of its important practical implications to investors and regulators. Many of the studies focused on linear interdependence between the markets. Ozturk et al. (2008), for example, examined the relationship between international crude oil prices and exchange rate in Turkey by employing cointegration and Granger causality tests on monthly dataset ranging from December 1982 to May 2006. The results show among others that crude oil prices granger-cause the USD/Turkish Lira exchange rate. Nikbakht (2009) applied cointegration to show that real oil prices may have been the dominant source of real exchange rate movements in seven OPEC countries for the January 2000 to December 2007 period. Contrary to these studies, Brahmasrene et al. (2014) found evidence of Granger causality from exchange rates to oil price in the short-term, but also reports causality from oil price to exchange rates in the long-term. Drachal (2018) examined the causal dynamics between spot oil price, exchange rates, and stock prices in Poland, the Czech Republic, Hungary, Romania, and Serbia for the 2000–2015 period. He reports amongst others that oil price negatively impacts exchange rates.

Some studies have also considered the interdependence across commodity prices and financial markets returns and volatility. Cifarelli and Paladino (2010) reported strong evidence to show that oil price shifts are negatively related to stock price and exchange rate changes, using daily data over the period 1992 to 2008. Ghosh (2011) further revealed that an increase in the oil price return leads to the depreciation of Indian currency vis-à-vis US dollar. However, using both fractional cointegration and copula techniques to examine volatility dependence between crude oil market and four US dollar exchange rates, Truchis and Keddad (2016) found amongst other evidence that dependence is sensitive to market conditions, increasing just before the 2008 market collapse and more recently, in the aftermath of the European debt crisis. Kohlscheen, Avalos and Schrimpf (2017) further demonstrated that there is a distinct commodity-related driver of exchange rate movements, even at fairly high frequencies. And that commodity prices predict exchange rate movements of 11 commodity-exporting countries in an in-sample panel setting for horizons up to two months, and systematic (pseudo) out-of-sample predictability

African evidence on interdependence between commodity market and foreign exchange markets has been provided through evaluation of returns characteristics and volatility transmission using the multivariate GARCH approach. Kin and Courage (2014) investigated the impact of oil prices on the nominal exchange rate South Africa by applying the GARCH model on oil prices and nominal exchange rate monthly data covering the period between 1994 and 2012. The results show that crude oil prices have a significant impact on nominal exchange rates. In addition, the results reveal that an increase in crude oil prices leads to a depreciation of the rand exchange rate. They conclude that crude oil prices are a very important variable in determining the strength of the rand and its volatility. A related South African study, Dumitrescu, Arezki, Freytag and Quintyn (2014) concluded that gold price volatility plays a key role in explaining both the excessive exchange rate volatility and current disproportionate share of speculative (short-run) inflows that South Africa has been coping with since the opening up of its capital account. An earlier study on equilibrium real exchange rate by MacDonald and Ricci (2004) found commodity price movements, amongst others, to have strong explanatory power on real value of the South African Rand. Onoja (2015) on the other hand, examined the dynamic relationship between oil price volatility and the real exchange rate in Nigeria using quarterly data for the period 1981 Q1 to 2009 Q4. Results obtained from the estimated error correction model did not show any dynamic short-run impact of oil price volatility on exchange rate.

A few African studies have further investigated volatility linkages across both financial and commodity markets. For example, Fowowe (2017) found evidence of bidirectional, but weak interdependence between the South African and Nigerian stock markets returns and oil market returns. The results for volatility spillovers show independence of volatilities between Nigeria stock markets and oil markets, while weak bi-directional spillovers were found between South African equity volatilities and oil volatilities. In a recent study on spillover effects between oil and food price volatility and the volatility of Uganda shilling per United States dollar exchange rate using the Generalized Vector Autoregressive (GVAR) approach and Multivariate Generalized Autoregressive Conditional Heteroskedasticity (MGARCH) techniques, Katusiime (2019) reported amongst others, existence of low levels of volatility spillover and market interconnectedness except during crisis periods, at which point cross-market volatility spillovers and market interconnectedness sharply and markedly increased

The existing empirical evidence shows that a good number of studies have examined the interdependence of crude oil and foreign exchange markets using different methodologies, but the scanty literature for Nigeria is glaring. In addition, existing evidence suggests that there is interdependence between volatility of crude oil prices and volatility of exchange rates but the direction varies. Hence, there is need for country specific evidence.

3 Sources of data and methodology

3.1 Methodology

To investigate the dynamic interdependence between crude oil prices and foreign exchange rates in Nigeria, we estimate BEKK representations of the multivariate GARCH model as outlined in Baba, Engle, Kraft and Kroner (1990), and Engle and Kroner (1995). The BEKK model, named after the authorship of the paper, presents a natural way to estimate the interaction within conditional variance of two or more series because of its capability to detect volatility interdependence among series, as well as persistence of volatility within each series. Bauwens, Laurent and Rombouts (2006) notes that the most obvious application of the multivariate GARCH (MGARCH) model is to study relations between the volatilities and co-volatilities of several markets. Many studies have applied the BEKK model to evaluate interdependence in regional and international markets as well as among sectors of the same market (see for example, Steeley, 2006; Malik & Ewing, 2009; Emenike, 2018; Katsiampa, Corbet & Lucey, 2019).

The first step in estimating the multivariate BEKK-GARCH parameters is to specify the mean equation. Hence, we specify the mean equation for crude oil and foreign exchange markets return as follows:

$$R_t = \mu + \theta R_{,t-i} + \varepsilon_t$$
$$\varepsilon_t = H_t^{1/2}\eta_t \qquad (1)$$

where $R_t = \left(R_t^{co}, R_t^{fm}\right)$` is a vector of returns of the crude oil market and foreign exchange market respectively, $\theta$ refers to a 2x2 matrix of coefficients, $\varepsilon_t = \left(\varepsilon_t^{co}, \varepsilon_t^{fm}\right)$` is the vector of error terms of conditional mean equation for crude oil and foreign exchange markets returns respectively, *t-i* is the autoregressive term in the mean equation in order to account for any autocorrelation in the markets returns. $\eta_t = \left(\eta_t^{co}, \eta_t^{fm}\right)$ is a sequence of independently and identically distributed (i.i.d) random errors; $H_t = \begin{pmatrix} h_t^{co} & h_t^{cofm} \\ . & h_t^{fm} \end{pmatrix}$ is conditional variance-covariance of crude oil and foreign exchange markets returns.

The next step is to specify the conditional variance-covariance equation. In order to avoid the increasing number of estimated parameters, typically the lag order of the model is chosen as 1, i.e., $p = q = 1$. This results in a parsimonious specification of the Engle and Kroner (1995) BEKK model thus:

$$H_t = CC` + A\varepsilon_{t-1}\varepsilon`_{t-1}A` + BH_{t-1}B` \qquad (2)$$

where *Ht* is the conditional variance matrix. *C, A*, and *B* are parameter matrices. C is a 2x2 lower triangular matrix with three parameters, *A* is 2x2 square matrix that shows how conditional variances correlate with past squared errors, and *B* is 2x2 square matrix that measures the effect of past conditional variances on the current conditional variances and the degree of persistence in the volatility of the markets. The parameter matrices from (Eq. 2) can be represented as follows:

$$\begin{bmatrix} h_{co,t} & h_{cofm,t} \\ . & h_{fm,t} \end{bmatrix} = \begin{bmatrix} c^0_{co} & c^0_{cofm} \\ 0 & c^0_{fm} \end{bmatrix}' \begin{bmatrix} c^0_{cofm} & c^0_{cofm} \\ 0 & c^0_{fm} \end{bmatrix} +$$

$$\begin{bmatrix} a^*_{co} & a^*_{cofm} \\ a^*_{fmoc} & a^*_{fm} \end{bmatrix}' \begin{bmatrix} \varepsilon^2_{co,t-1} & \varepsilon_{co,t-1}\varepsilon_{fm,t-1} \\ \varepsilon_{co,t-1}\varepsilon_{fm,t-1} & \varepsilon^2_{fm,t-1} \end{bmatrix} \begin{bmatrix} a^*_{co} & a^*_{cofm} \\ a^*_{fmco} & a^*_{fm} \end{bmatrix} + \quad (3)$$

$$\begin{bmatrix} b^*_{oc} & b^*_{cofm} \\ b^*_{fmco} & b^*_{fm} \end{bmatrix}' \begin{bmatrix} h_{co,t-1} & h_{cofm,t-1} \\ h_{fmco,t-1} & h_{fm,t-1} \end{bmatrix}' \begin{bmatrix} b^*_{oc} & b^*_{cofm} \\ b^*_{fmco} & b^*_{fm} \end{bmatrix}$$

where $h_{co,t}$ denotes the conditional variance of the crude oil market, $h_{cofm,t}$ the covariance of crude oil and foreign exchange markets, and $h_{fm,t}$ the conditional variance of foreign exchange market. Statistical significance of the diagonal coefficients $a_{co,t}$ ($a_{fm,t}$) would suggest that the current conditional variance of $h_{co,t}$ ($h_{fm,t}$) is correlated with its own past squared errors, while the statistical significance of the lagged variance $b_{co,t}$ ($b_{fm,t}$) indicate that the current conditional variance of $h_{co,t}$ ($h_{fm,t}$) is affected by its own past conditional variance. Similarly, the statistical significance of the off-diagonal coefficients $a_{cofm,t}$ and $b_{cofm,t}$ will indicate evidence of shock and volatility transmission effects from the crude oil market to the foreign exchange market, whereas the statistical significance of the off-diagonal coefficients $a_{fmco,t}$ and $b_{fmco,t}$ will show evidence of volatility transmission effects from the foreign exchange market to the crude oil market.

The matrix multiplication leads to equations (4) and (5) where, $\mathrm{h}_{co,t+1}$, and $\mathrm{h}_{fm,\ t+1}$ are conditional volatilities of crude oil market and foreign exchange market respectively, $\mathrm{h}_{cofm,\ t}$ is the conditional covariance, $\varepsilon^2_{co,t}$, $\varepsilon^2_{fm,t}$ and $\varepsilon_{co,t}\varepsilon_{fm,t}$ are the lagged own squared and cross-market random shocks.

$$h_{cp,t+1} = c_{co}^2 + a_{co}^2\varepsilon_{co,t}^2 + 2a_{co}a_{cofm}\varepsilon_{fm,t} + a_{fmco}^2\varepsilon_{fm,t}^2 + b_{co}^2 h_{co,t}^2 + 2b_{co}b_{cofm}h_{cofm,t}h_{cofm,t} + b_{fmco}^2 h_{fm,t} \quad (4)$$

$$h_{fm,t+1} = c_{cofm}^2 + a_{cofm}^2\varepsilon_{co,t}^2 + 2a_{cofm}a_{fm}\varepsilon_{co,t}\varepsilon_{fm,t} + a_{fm}^2\varepsilon_{fm,t}^2 + b_{cofm}^2 h_{co,t}^2 + 2b_{cofm}b_{fm}h_{cofm,t} + b_{fm}^2 h_{fm,t} \quad (5)$$

Maximum likelihood estimates of the parameters in equations (4) and (5) were obtained using the Broyden, Fletcher, Goldfarb, and Shanno (BFGS) algorithm. The likelihood element for an *n*-vector at time *t* can be estimated as follows:

$$\mathrm{L}(\theta) = -\frac{1}{2}\log 2\pi - \frac{1}{2}\log|\Sigma_t| - \frac{1}{2}\varepsilon_t'\Sigma_t^{-1}\varepsilon_t \quad (6)$$

where θ is the parameter vector to be estimated.

One way to assess the adequacy of a multivariate GARCH model is to examine the standardised residuals and squared standardized residuals for autocorrelation and heteroscedasticity respectively. The estimated standardized residuals and squared standardized residuals, according to Enders (2004), should be serially uncorrelated and should not display any remaining conditional volatility. The adequacy of the multivariate GARCH model fitted to the crude oil and foreign exchange markets returns series were evaluated by testing the standardised residuals for independence (Tsay, 2005). If the mean model is adequately specified, the standardised residuals would be uncorrelated. Likewise, a good variance model would display uncorrelated squared standardized residuals.

The robustness of the multivariate GARCH models was therefore, evaluated using the following diagnostics tests: Autocorrelation function (ACF), Ljung and Box (1978) Q test statistic, and Engle (1982) Lagrange multiplier (LM) test. The ACF and L-B Q test statistics were used to test the null hypothesis of no autocorrelation in the estimated residuals and squared standardised residuals up to a specific lag. The LM test was used to examine the squared residuals for existence of any remaining ARCH effect up to lag p. All the equations specified in this paper were estimated using Regression Analysis for Time Series (RATS) Software, Version 9.0.

3.2 Description of data

Monthly observations on the crude oil prices (COP) and Naira/USD bureau de change exchange rates (EXr) were obtained from the Central Bank of Nigeria (CBN) statistics databank for the period ranging from January 2002 to December 2014, totalling 156 observations for each series. This time period was chosen to capture the fundamental changes made to implement advanced information and communication technology for the operation of the Nigeria financial markets as well as based on availability of data. In addition, the period captured both the boom and crisis periods in both the crude oil and foreign exchange markets in Nigeria. The price of crude oil, for instance, increased on average from US $25 in 2002 to record high of US $147 per barrel in the middle of 2008. However, the oil price dropped sharply to US $46 per barrel towards the end of 2008. The chosen study period therefore captured the period before and after the global financial crisis. The COP and EXr series were transformed to returns series by taking their first log difference.

4 Empirical results and discussions

4.1 Preliminary analysis

Descriptive statistics

Figure 1 presents time series graph of the log-level and return series of the crude oil and foreign exchange for the study period. Notice from Figure 1 that the crude oil market exhibited strong upward trend from January 2002 which attained the peak in the second half of 2008, before moving downward, as a result of the global financial crisis. The market price of crude oil rebounded from the third quarter of 2009 and remained fairly stable until June 2014 when it started to decline. Notice also that the series appears to be trending. The level series graph of the foreign exchange market displayed in Figure 1 also appears nonstationary. The Naira/US$ exchange rate started declining from the second quarter of 2006 and attained the least rate for the sample period in April 2008, before moving upward till the first quarter of 2009. It became fairly stable from 2010 till second quarter of 2014 when started moving up.

The time series graph of the return series of the crude oil and foreign exchange markets show that the crude oil return series were above its average value at the inception of the study period. This was followed by wide fluctuations in the return series with many noticeable spikes. Observe that the most negative changes in the crude oil return series was recorded during the period of the global financial crisis.

However, the series show mean reversion tendency. This is easily seen in the ability of each series to return to the mean after a deviation. Another noticeable feature of Figure 1 is that the crude oil market return is below its average. Given the mean reversion tendency of the returns data, the market return series will likely rise, all things being equal, in the long-run. This is so because stationary series will always return to their mean irrespective of how far they deviate; that is one of the desirable attributes of stationary series and the reason for their choice in econometric estimation. The return series of the foreign exchange market displays the four major features: (i) the exchange rate returns was above its average at the inception of the study period, (ii) the very high volatility during the global financial crises is obvious in the series, though in different directions and other high and low volatility can be seen, (iii) the mean reversion tendency of exchange rate returns, and (iv) the above average returns of the foreign exchange market returns series. The last feature implies that, all things being equal, the exchange rate will fall in the next period.

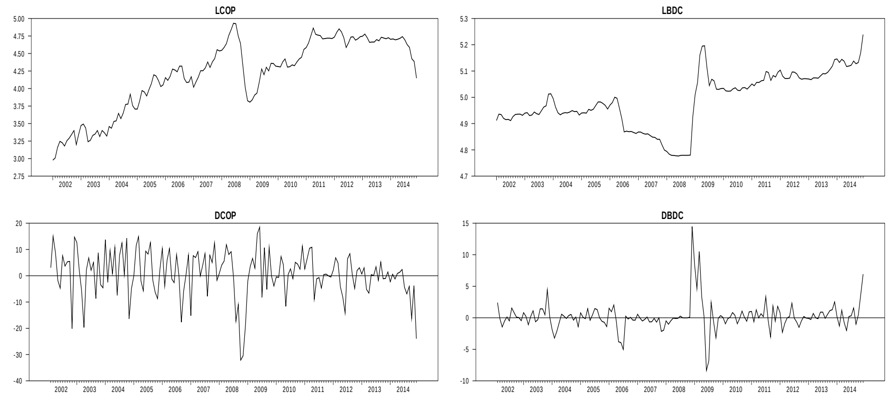

Figure 1: Graph of Crude Oil Prices and Naira/US$ Exchange Rates Level and Return Series January 2002 to December 2014

Table 1 provides some summary statistics for the crude oil and foreign exchange markets returns series. Notice from this table that mean monthly returns for all the markets are positive. The annualized monthly mean returns are 9,05% and 2,53%, for the crude oil and foreign exchange markets respectively. The annualized monthly standard deviation for the crude oil and foreign exchange markets returns are 10,27% and 5,29% respectively. Notice that the crude oil market has higher rate of change as well as higher variability. Skewness measures symmetry of returns distribution. Negative or positive skewness suggests return asymmetry whereas zero skewness indicates symmetry in the returns distribution. From Table 1, the returns distribution of crude oil is negatively skewed whereas that of the foreign exchange market is positively skewed. Skewness plays an important role in asset pricing. Negative skewness suggests that there are more negative observations in the return distributions of crude oil than in normal distribution. Positive skewness, on the other hand, indicates that there are more positive observations in the return distribution of the foreign exchange market. Many empirical literatures find that speculation is the reason for the skewness in the return distribution of financial assets returns and that skewness varies with time (see for example, Singleton & Wingender, 1986; Harvey & Siddique, 2000; Liu, Zhang, & Wen, 2014). Indication of negative skewness in the return distributions of the crude oil is not surprising, given the devastating impact of the GFC on the markets. Similarly, positive skewness of the foreign exchange market return is expected because the Naira/US$ exchange rate has increased more often than it decreased. Kurtosis provides summary information about the shape of a return distribution. Table 1 shows that the two markets returns are leptokurtic. Excess kurtosis of crude oil and foreign exchange markets are 1,7 and 13,1 respectively. An implication of leptokurtosis is that extreme observations are much more likely to occur. This phenomenon is most acute in the case of the foreign exchange market. The Jarque-Bera test results are significant at 1% level, suggesting that normality assumptions for the two market series are doubtful.

Table 1: Univariate statistics for crude oil and foreign exchange rate returns in Nigeria

Variable	Mean	Std. Dev.	Skewness	Kurtosis	J-B Stat.
Oil	0,754	8,781	-0,970 (0,000)	1,742 (0,000)	43,938 (0,000)
Forex	0,211	2,328	1,939 (0,000)	13,123 (0,000)	1209,577 (0,000)

Note: *P*-values are displayed as (,). Std. Dev. and J-B stat. are the standard deviation and Jarque-Bera statistics for the market returns, respectively.

Estimates from unit roots tests

Table 2 presents results of unit roots tests on the natural logarithmic level and return series of crude oil and foreign exchange markets in Nigeria. Testing methodologies are Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test. Critical value of the tests was taken at the 5% level of significance to avoid the problem of accepting a false null hypothesis. The critical value of both the ADF and PP tests is -3,439 for the study period. Notice from Table 2 that the calculated values of the ADF test statistics is more than the ADF critical tau value at 5% significance level. This indicates that the crude oil and foreign exchange markets level series contain unit root at the 5% significance level. In other words, crude oil and foreign exchange markets series are not stationary at level. The PP estimates uphold the results of the ADF test. The market returns series shows, however, that both the ADF and PP computed critical tau values are all less than the 5% critical tau value. This suggests that the crude oil and foreign exchange markets returns series do not contain unit root at the 5% significance level. These results indicate that the market returns series are stationary.

Table 2: Results unit root tests for crude oil and foreign exchange markets series in Nigeria

Variables	5% critical value	Augmented Dickey Fuller	Phillip-Perron	Augmented Dickey Fuller	Phillip-Perron
		Level Series		Return Series	
Oil	-3,4394	-1,921	-1,943	-9,451**	-9,576**
Forex	-3,4394	-2,662	-2,255	-7,212**	-7,276**

Note: ** refers to 1% statistical significance levels.

Estimates for serial correlation

Table 3 reports estimates of autocorrelation, lag analysis, and heteroscedasticity for the crude oil and foreign exchange markets returns series. Panel A of Table 3 displays estimates of autocorrelation functions (ACF) for the crude oil and foreign exchange markets returns series, and Ljung-Box Q-statistic used for testing significance of the ACF. The ACF test is conducted, up to lags 12, to ascertain whether the return series are independent of each other or serially correlated. The nature of autocorrelation of the markets returns series are necessary to define appropriate conditional mean equation (Strydom & Charteris, 2011). Notice from Ljung-Box Q-statistic that the crude oil and foreign exchange markets returns series exhibit evidence of serial correlation at the 5% significance level. The existence of serial correlation in the markets returns series give impetus to estimation of autoregressive (AR) specification which would remove time dependence in the residuals.

Panel B of Table 3 reports estimate of Bayesian information criterion (BIC) lag analysis conducted to select appropriate lag lengths for the crude oil and foreign exchange markets return series. Rachev, Mittnik, Fabozzi, Focardi, and Jasic (2007:

293) state that if the conditional mean is not specified adequately, then construction of consistent estimates of the true conditional variance would not be possible and statistical inference and empirical analysis might be wrong. For this purpose, 12 lags of the BIC were estimated to select the appropriate autoregressive lag length required to contain serial correlation in residuals of the crude oil and foreign exchange markets returns. Notice from Panel B of Table 3 that the two markets returns require autoregressive lag one (AR_1) model.

Panel C of Table 3 presents estimates for the test of heteroscedasticity estimated using ARCH-LM test for the squared residual of the crude oil and foreign exchange markets returns series. Notice the existence of heteroscedasticity (i.e., ARCH effect) in the markets returns series, up to lags 6, at the 5% significance levels. The presence of heteroscedasticity in the series is a justification for the estimation of GARCH model.

Table 3: Serial correlation, lag selection and heteroscedasticity analyses

Lags	Crude oil	Exchange rates
Panel A: Ljung-Box Q Statistics for the Series		
1	0,245 (0,001)	0,458 (0,000)
6	-0,186 (0,004)	-0,232 (0,000)
12	-0,009 (0,001)	-0,015 (0,000)
Panel B: Bayesian information criterion (BIC) lag selection for the series		
0	-4,839	-7,494
1	-4,866*	-7,682*
2	-4,839	-7,655
Panel C: ARCH-LM test for heteroscedasticity in squared return series		
1	10,668 (0,001)	2,001 (0,002)
3	4,004 (0,008)	6,142 (0,000)
6	2,537 (0,031)	3,508 (0,002)

Note: The estimates of the ACF were abridged for want of space.

4.2 BEKK-GARCH (1,1) results of volatility interdependence between crude oil and foreign exchange markets in Nigeria

This section reports results of the bivariate BEKK-GARCH (1,1) model estimated to evaluate the nature and significance of volatility interdependence between crude oil and foreign exchange markets in Nigeria. As can be seen from Table 4, the estimates of the diagonal elements, $A_{co,co}$, $A_{fm,fm}$, $B_{co,co}$ and $B_{fm,fm}$, are all statistically significant at the 5% level. These show that news about volatility from the previous period and volatilities of the crude oil and foreign exchange markets returns have strong influence on the current period volatilities of the markets. These findings are partly related to May and Farrell (2018) who amongst others document evidence of volatility persistence in the key nominal exchange rates of the South African rand.

The off-diagonal elements of matrices A and B capture the nature of volatility interdependence between the crude oil and foreign exchange markets. From the off-diagonal elements of matrix A, notice that there is statistically significant negative unidirectional shock transmissions from crude oil market to foreign exchange market ($A_{co,fm}$) at the 5% significance level. The calculated *t*-statistic (-7,33) and the *p*-value (0,000) of the off-diagonal parameter $A_{(og,fm)}$ are greater than the critical *t*-statistic (1,960) and less than the *p*-value (0,050) at 5% significance level. This indicates that negative information coming from the crude oil market influences volatility in the foreign exchange market. In other words, a decrease in the crude oil price results in an increase in the volatility of the foreign exchange market.

Results of the off-diagonal elements of matrix B also show evidence of a unidirectional volatility transmission from crude oil market to foreign exchange market. The calculated *t*-statistic (2,741) of the off-diagonal parameter $B_{og,fm}$ is greater than the critical *t*-statistic at 5% significance level (1,960). Similarly, the *p*-value (0,006) of the off-diagonal parameter $B_{og,fm}$ is less than the significance level (0,05). Hence, there is significant unidirectional negative shock and volatility transmission from crude oil market to foreign exchange market in Nigeria. Evidence of negative unidirectional volatility transmission from crude oil market to foreign exchange market provides support for partial interdependence between the markets. The evidence of negative unidirectional volatility transmission from crude oil market to foreign exchange market in Nigeria is similar to earlier studies. For example, Ozturk et al. (2008), reported that crude oil prices granger-cause the USD/Turkish Lira exchange rate. Similarly, Drachal (2018) found that oil prices have a strong negative impact on exchange rate in Czech Republic, Hungary, and Romania. Kin and Courage (2014) also found that an increase in oil prices leads to a depreciation of the rand exchange rate in South Africa.

The negative unidirectional shock and volatility transmission from crude oil market to foreign exchange market in Nigeria may be explained by the fact that crude oil, which is the major source of government revenue in Nigeria, is priced in the US dollar. Central Bank of Nigeria receives proceeds of crude oil transactions, on behalf of the government, in US dollar and auctions US dollar at the foreign exchange market biweekly to meet the insatiable desires of the import-dependent Nigerians. Thus, volatility of the crude oil market would most likely transmit to the foreign exchange market since the country depend on the US dollar to buy both the necessary commodities needed to develop the economy and to provide for the frivolous demands as well as to sell crude oil. In addition, importation of petrol is a substantial source of demand for dollar in Nigeria's foreign exchange market and a drain on Nigeria's external reserve. Nnodim and Asu (2015), for example, reported that the Kaduna refinery would save about $5,33m daily for the country when it attains ninety percent (90%) production capacity in the first quarter of 2016. Similarly, Boyo (2015) reported that fuel accounts for over 40% of Nigeria's total foreign exchange expenditure on imports annually, and that the consolidated foreign exchange requirement for genuine fuel importers exceeded $5bn annually. Such huge amount of foreign currency could be conserved if the country harnesses her refining capability, and channelled to strengthening infrastructural facilities in health, education, and other productive sectors. The strong demand for petrol, because of its importance to economic activities such as transport, manufacturing, heat, etc, contributes not only to strengthen the dollar against Nigerian Naira but also to strengthen integration between the two markets.

Table 4: GARCH-BEKK results of volatility interdependence between crude oil and foreign exchange market in Nigeria

Parameters	Coefficient	*t*-statistic	*p*-value
$C_{(co,co)}$	0,0615	3,1287	0,0017
$C_{(fm,co)}$	-0,0022	-1,4132	0,1575
$C_{(fm,fm)}$	0,2264	2,7708	0,0055
$A_{(co,co)}$	0,1407	2,0808	0,0374
$A_{(co,fm)}$	-0,1009	-7,339	0,0000
$A_{(fm,co)}$	0,1576	0,4683	0,6395
$A_{(fm,fm)}$	0,6100	7,4948	0,0000
$B_{(og,og)}$	0,6652	2,6612	0,0077
$B_{(co,fm)}$	0,0371	2,7411	0,0061
$B_{(fm,co)}$	-0,4356	-1,2872	0,1980
$B_{(fm,fm)}$	0,6476	11,9348	0,0000

Note: Author's computation

Univariate and multivariate diagnostic tests were conducted to ascertain the adequacy of BEKK-GARCH (1,1) model fitted to the crude oil and foreign exchange markets residual and squared residual series. As shown in Table 5, the univariate Ljung-Box statistics give Q(6) = 10,0 and Q^2 (6) = 16,7, which correspond to *p*-values of 0,12 and 0,10 respectively for the residuals and squared residuals of the crude oil market returns model. For foreign exchange market returns model, we have Q (6) = 3,98 and Q^2 (6) = 6,67 with *p*-values of 0,68 and 0,35 respectively for the residuals and squared residuals. These imply that the Q-statistics for the residual series and squared residual series of crude oil and foreign exchange markets returns are insignificant, suggesting that there are no serial correlations in their residuals and squared residuals. The multivariate ARCH-LM and Ljung-Box Q statistics also show absence of heteroscedasticity and serial correlation in the squared standardized residuals and standardized residuals of the bivariate BEKK-GARCH model. Thus, both the univariate and multivariate diagnostic tests confirm adequacy of the fitted model.

Table 5: Diagnostic test results for GARCH-BEKK model of volatility interdependence between crude oil and foreign exchange market in Nigeria

	Statistic	*p*-value	*p*-value (χ^2)
Q_{co} (6)	10,008	0,124	
Q_{co}^2 (6)	16,669	0,101	
Q_{fm} (6)	3,976	0,679	
Q_{fm}^2 (6)	6,670	0,352	
MV LM {6}	2,140		0,906
MV Q (6)	15,064		0,109

Note: Author's computation Q and Q^2 are univariate Ljung-Box statistics for the residuals and squared residuals respectively of each market, estimated up to lags 6. MV LM and MV Q are multivariate ARCH-LM and Ljung-Box Q statistics.

5 Conclusions

This paper evaluated the nature of interdependence between crude oil and foreign exchange markets in Nigeria using BEKK-GARCH (1,1) model. The results obtained from the model show evidence of volatility clustering and volatility persistence in the crude oil and foreign exchange markets returns. The results also provide evidence to show that there is significant unidirectional shock and volatility transmission from crude oil market to foreign exchange market in Nigeria. Evidence of significant unidirectional shock and volatility transmission is an indication of partial integration between the crude oil market and the foreign exchange market in Nigeria. Partial interdependence between crude oil market and foreign exchange market in Nigeria has implications for risk management, foreign exchange and crude oil revenue management policy-making. Overall results from this study indicate that the volatility of crude oil prices is a very strong determinant of foreign exchange volatility in Nigeria. We therefore suggest that Nigerian government should, as a matter of urgency, deregulate the downstream oil sector. This will encourage investment in refining of crude oil into gasoline, diesel, jet, and other fuels, and ensure that the billions of dollars spent on importation of crude by-products from abroad are retained in Nigeria to shore-up external reserves and reduce the demand-pressure on dollars. This policy will also enhance stability of Naira/US$ exchange rates thereby control the speed of depreciation of the Naira.

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