OIL-EXCHANGE RATE VOLATILITIES AND RETURNS NEXUS

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Abstract

The study evaluates the channel of volatilities and returns between global oil prices and exchange rates of 21 developing countries. The structural vector autoregression (SVAR) findings are that oil-producing and exporting countries would have their exchange rates fluctuate slightly due to changing oil prices. For Markov-regime switching estimations, whereas, exchange rate volatility does not significantly influence volatility in oil prices at both regimes of flexible and fixed exchange rates, there is the presence of significant volatility spill-over from oil prices to exchange rates. Oil price movements do significantly induce appreciation or depreciation of exchange rates. In effect, volatilities in exchange rates do not trigger volatilities in oil prices but positively and considerably influenced crude oil returns in the fixed regime by 0.59%. Notwithstanding the 0.092 low transition probability, all other probabilities that the influence of volatility in the exchange rate on oil market volatility would persist are high for both flexible and fixed regimes of exchange rates. The significant positive coefficients of exchange rates together with high transition probabilities reported are indicative of rising exchange rates, implying devaluation and hence, a negative influence on oil returns and prices. Market agents can therefore diversify risks by investing in oil markets and forex markets independently.

Keywords: Exchange Rate Volatilities, Oil Price Volatilities, Returns, Persistence, Markov-Regime Switching Regression, Transition Probabilities

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1. INTRODUCTION

Crude oil prices, degree of openness, exchange rate flexibility, existing policy buffers, and economic complexity may all have an impact on macroeconomic policy objectives in developing and growing economies compared to industrialized nations. Market players and investors may learn crucial information from fluctuations in the price of crude oil and the currency rate. According to Hu and Xiong (2013), such information is especially useful for investors and consumers engaged in speculative trading on futures markets. Given the effects of changing oil prices on energy expenses, it is useful for planning household expenditures as well. Oil has a significant role in every economy. In light of the aforementioned scenario, modifications to the global oil market manifesting in a decline in oil demand while maintaining the same level of supply would have severe negative effects on the health of the economy (Ogbonna & Amuji, 2018).

In particular, a decline in the purchasing power of the local currency results in an increase in the general price level brought on by the increase in the price of imported inputs due to a drop in oil consumption brought on by the global COVID-19 epidemic (Ogbonna & Appah, 2012; Dabor et al., 2023; Umoru et al., 2023a, 2023d). In contrast, domestic prices and manufacturing costs fell for net oil importers, and they accumulated foreign reserves, which caused the domestic currency to appreciate and increased demand for local currency to outpace their stockpiles. The paper investigates a pattern of volatility spillover between the oil market and 21 developing African nations' currency exchange rates. Specifically, we attempted to evaluate the channel of volatilities and returns between global oil prices and exchange rates of 21 African countries.

Despite the extensive empirical literature on the influence of oil price volatility (henceforth denoted as *oprvol*) on the currency rate in Africa, most studies by researchers focus on the influence of *oprvol* on the currency rate of exchange in Africa. This indicates a gap in the literature, particularly on how volatility in exchange rates influences oil price movements in Africa. Hence, the recent study aims to address the existing empirical gap. By empirically evaluating the oil-exchange rate volatilities and returns nexus, the study added to economics literature regarding the direction of causality between volatility in currency rates of exchange of 21 developing African countries and *oprvol* in contrast to existing research that has studied the role of oil price movements on exchange rate dynamics only. Moreover, with the Markov-switching regression methodology, the study provides a guide for policymakers in terms of regime dependency/independency of the effect of volatility in exchange rates on oil price volatility, the outcome of oil price volatility on exchange rate returns, oil returns effect of exchange rate volatility (*exrvol*), and *exrvol* effect due to *oprvol*. With the significant transition probabilities, the study reveals the persistence in the influence of volatility in the exchange rate on oil market volatility at both fixed and flexible regimes of exchange rates.

The remainder of the paper is organized as follows. Section 2 reviews the literature relevant to the study topic. Section 3 explains the methodology and relevant research materials. Section 4 has the empirical results and the discussions, that is, it comprised tables that summarized estimation output with corresponding interpretations, and ensuing policy implications. Finally, the conclusions are given in Section 5.

2. LITERATURE REVIEW

Both theoretical and empirical literature has established some levels of strong volatility spillover effects, non-linear relations, and causality between volatilities of exchange rates and oil prices (Beckman et al., 2020; Qiang et al., 2019). In terms of theoretical discussions, Krugman (1980) observed that portfolio decisions made by oil-exporting and oil-importing nations were primarily responsible for the discrepancies in foreign exchange markets of the 1970s. As oil proceeds are invested in assets with a predominance of the US dollar, there will initially be a favorable link. The connection eventually becomes negative, though, as the Organization of the Petroleum Exporting Countries (OPEC) spends more money as a consequence of increased income from higher oil prices as a result of industrial countries' demand for the produced goods. The US currency will rise in the near term but not over the long run if OPEC imports are made outside of the United States. According to Golub (1983), higher oil prices cause a wealth shift from oil consumers to oil exporters.

The elasticity approach upholds that depending on a country's importer's responsiveness to demand, the exchange rate fluctuates in reaction to fluctuations in oil prices. The imports' elasticity, however, determines the speed of fluctuation of imports. If demand for oil imports is rigid, a rise in oil prices results in a weakening of the importing nation's currency. When oil prices rise (fall), the importing nation needs to spend more (less) of its own money to purchase the same amount of oil as before. Consequently, the currency of importing nations would depreciate (appreciate) (Nouira et al., 2018). Nkomo (2006) argued that if the price of a nation's export good (oil) increases, the products become comparably costlier on the global market. As a result, oil-importing nations will lower their imports. Blomberg and Harris (1995) based explanations of the effects of exchange rates on fluctuations in oil prices on the concept of one price for traded products. They demonstrate that because oil is a uniformly valued commodity that is sold globally and priced in dollars, a drop in dollars lowers the cost of oil for foreign consumers relative to the cost of their goods denominated in the same currency.

In the current literature, many scholars have empirically investigated the influence of the volatilities in oil price movements and exchange rates of different countries on different variables including foreign reserves (Umoru et al., 2023c; Umoru et al., 2023b; Umoru et al., 2023e). Also, authors such as Depren et al. (2023), Devpura et al. (2021), Kartal (2021), Kartal et al. (2021), Augustin et al. (2020), Narayan et al. (2021), have studied foreign exchange (FX) rates from credit risk, volatility, stock market, and oil prices outlooks. The generalized autoregressive conditional heteroskedasticity (GARCH) analysis of Isah and Ekeocha (2023) reveals that the fluctuations in global oil prices were responsible for the persistence of *exrvol* during COVID-19. Deploying the threshold GARCH model to investigate the volatilities between oil prices and exchange rate, Hlongwane et al. (2022) were able to establish that exchange rates in South Africa were negatively and significantly influenced by oil prices. As it were, regarding the path of interconnection between currency rates and oil prices, there is disagreement.

The following studies, namely, Gao et al. (2022), Adi et al. (2022), Bouazizi (2022), Igbinovia and Ogiemudia (2021), Musa and Maijama'a (2021), Castro and Jime'nez-Rodrı'guez (2020), Monday and Abdulkadir (2020), Musa et al. (2020), Umoru et al. (2018), etc. found evidence that oil price movements influenced exchange rates and not the other way round. Gao et al. (2022) found nonlinear both ways causation between currency exchange rates and oil price increases in India and Bangladesh respectively. The same authors reported one-way causation from oil price variations to exchange rate movements in Sri Lanka and Pakistan respectively. Adi et al. (2022) reported that one-way volatility and shock from Brent oil price (*Bop*) increases affect the exchange rates market. Further results that emanated from Adi et al. (2022) include some two-way shock and volatility spillover from USD/NGN to *Bop* and from oil prices to USD/NGN. The author also reported asymmetric shocks on exchange rates. Basing findings on vector autoregression (VAR) impulse responses, the results of Bouazizi (2022) established a distribution effect of the unpredictability of oil prices on foreign exchange markets.

In Venezuela, Duan et al. (2021) reported a bidirectional volatility spillover spread between exchange rates and oil prices. According to Igbinovia and Ogiemudia (2021), in the short-run analysis, oil price variability played no significant negative role in stimulating variations in exchange rates whereas, in the long-term analytics, the oil price was found to play an insignificant positive role in inducing variations in the USD/NGN exchange rate. Musa and Maijama'a (2021) reported a one-way causality running from oil prices to exchange rates. Castro and Jime'nez-Rodrı'guez (2020) deployed monthly series and found considerable exchange rate movement to shocks in oil prices. In particular, the authors reported that the exchange rate appreciated following an increase in oil prices. The findings of Castro and Jiménez-Rodríguez (2020) further maintained that the United States's real effective exchange rate (REER) reacted differently across time whereas, in the short-term period, shocks in oil prices stimulated currency devaluation.

According to Wen et al. (2020), spillovers of exchange rate volatilities to crude oil market volatilities are stronger than those from oil to exchange rates. Beckmann et al. (2020) revisited theory and evidence with findings that exchange rate movements are not a determining factor for forecasting oil prices in the USA. Monday and Abdulkadir (2020) also established the considerable impact of volatility in oil prices on volatility in exchange rates in Nigeria. In Ghana, Zankawah and Stewart (2020) established significant volatility spillover from oil prices to the exchange rate market as made evident from multivariate GARCH-BEKK analysis. In Japan, Devpura (2020) found insignificant volatility spillovers from oil prices to the exchange rate of the Japanese currency (JPY). In Azerbaijan, Mukhtarov et al. (2020) based evidence on the vector error correction model (VECM) model and found that the negative effect of volatility spills over from oil prices to the exchange rate. On his part, Villarreal-Samaniego's (2020) based analysis of the autoregressive distributed lags (ARDL) model reported that variations in the exchange rate are inversely diffused to oil prices. Gomez-Gonzalez et al. (2020) found that spillovers of variations in FX markets are transmitted to oil prices as made evident by the Granger causality model.

Musa et al. (2020) found a negative influence of oil price variations on the exchange rates in both economic periods of analysis. Basing an analysis of the VECM, Umoru et al. (2018) found empirical evidence that established that oil prices heighten exchange rate instability in Nigeria. In Mexico, Singhal et al. (2019) based empirical investigations on the ARDL model and successfully established that the exchange rate was significantly fluctuated by the variations in oil price. In Azerbaijan, Mukhtarov et al. (2019) basing analysis on the VECM model reported that variations in oil prices in 2014 resulted in devaluation in the exchange rates. Also, in Indonesia, Narayan et al. (2019) implemented the ARDL model and reported a long-term association between variations in the real exchange rates and oil prices. On the contrary, Igbinovia and Ogiemudia (2021) found a non-significant exchange rate volatility effect of oil price variability in Nigeria. Olayungbo (2019) reported that the oil price movement does not prompt exchange rate volatility in Nigeria. In a study of dollar-oil price variations in the USA, Anjum (2019) implemented both the univariate and bivariate GARCH models and found zero evidence of volatility transmission between USD and oil prices when no provision is made for structural breaks. Conversely, the author reported significant volatility transmission between the USD and oil prices when provision is made to control for the possibility of structural breaks. In India, Bhattacharya et al. (2019) found evidence in favor of an insignificant causal effect between variations in exchange rates and oil price movements.

In terms of nonlinear association in sub-Saharan African countries, Baek and Kim (2020) established that real exchange rates were asymmetrically affected by the instabilities in oil prices with exchange rates reacting mostly more to the upsurge in oil prices than to a drop in the same. In India and China, Khraief et al. (2021) utilized the NARLD model to establish the non-linear influence of the variations in oil prices on exchange rates only in the presence of time-series noise. Sanusi (2020) reported that oil price movements had a long-run asymmetric effect on the instability of the exchange rate, which was only sizeable following a drop in price as against an insignificant influence due to a rise in oil price. For the Nigerian economy, Fasanya et al. (2022) reported that a rise in oil prices stimulates the depreciation of the Nigerian currency (NGN) to the USD. In Indonesia, Saenong et al. (2020) based analysis on both the ARDL and a nonlinear ARDL (NARDL) models with a monthly data set and established that none of the exchange rate and oil price variations impacted bond yields symmetrically. Ji et al. (2019) reported a significant positive lower-tail link between crude oil and the exchange rate and a significant negative upper-lower-tail link between oil volatility and the US dollar index. In addition, the authors found some asymmetry risk spillover from crude oil to FX markets of the US and China. In China, Zhu and Chen (2019) based evidence on the NARDL modeling technique and established irregularity in volatility risk transmission between *exr* and *opr*. The NARDL regression estimations of Jung et al. (2019) obtained an asymmetric causal effect running from the USD/CAD exchange rate to real oil price. The NARDL empirical evidence obtained by Kumar (2019) showed an asymmetric impact on the exchange rate due to lagged period shocks in oil prices. In Malaysia and Indonesia, Kisswani et al. (2019) applied quarterly series to a NARDL model and reported asymmetry in the influence of oil prices on the exchange rates of both countries. Other studies namely, Salisu and Mobolaji (2013), Selmi et al. (2012), and Ding and Vo (2012) all established some forms of transmission between exchange rate movements and movements in oil prices. In Tunisia and Morocco, Selmi et al. (2012) obtained one-way transmission moving from oil prices to exchange rates. Similar results were obtained for the Nigerian economy by Salisu and Mobolaji (2013).

3. RESEARCH METHODOLOGY

The SVAR model was deployed in this study to measure the reaction of oil price volatility to exchange rate volatility and vice versa. In particular, the SVAR equation has the following form:

$$\begin{bmatrix} 1 & \beta_{12} \\ \beta_{22} & 1 \end{bmatrix} \begin{bmatrix} oprvol_t \\ exrvol_t \end{bmatrix} = \begin{bmatrix} \mu_{10} \\ \mu_{20} \end{bmatrix} + \begin{bmatrix} \vartheta_{11} & \vartheta_{12} \\ \vartheta_{21} & \vartheta_{22} \end{bmatrix} \begin{bmatrix} oprvol_{t-1} \\ exrvol_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{oprvol} \\ \varepsilon_{exrvol} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} 1 & \rho_{12} \\ \rho_{22} & 1 \end{bmatrix} \begin{bmatrix} Ropr_t \\ Rexr_t \end{bmatrix} = \begin{bmatrix} \delta_{10} \\ \delta_{20} \end{bmatrix} + \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} \begin{bmatrix} Ropr_{t-1} \\ Rexr_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{Ropr} \\ \varepsilon_{Rexr} \end{bmatrix} \quad (2)$$

Alternative specifications of equations (1) and (2) are given in eq. (3), (4), (5), and (6) respectively:

$$oprvol_t = \mu_{10} + \beta_{12} exrvol_t + \vartheta_{11} oprvol_{t-1} + \vartheta_{12} exrvol_{t-1} + \varepsilon_{oprvol} \quad (3)$$

$$exrvol_t = \mu_{20} + \beta_{22} oprvol_t + \vartheta_{21} exrvol_{t-1} + \vartheta_{22} oprvol_{t-1} + \varepsilon_{exrvol} \quad (4)$$

$$Ropr_t = \mu_{30} + \beta_{32} Rexr_t + \vartheta_{31} Ropr_{t-1} + \vartheta_{32} Rexr_{t-1} + \varepsilon_{Ropr} \quad (5)$$

$$Rexr_t = \mu_{40} + \beta_{42} Ropr_t + \vartheta_{41} Rexr_{t-1} + \vartheta_{42} Ropr_{t-1} + \varepsilon_{Rexr} \quad (6)$$

where: $oprvol_t$ and $Ropr_t$ are the current oil price volatility and returns; $oprvol_{t-1}$ and $Ropr_{t-1}$ are the one-period lagged oil market volatility and returns; $exrvol_t$ and $Rexr_t$ are the current exchange rate volatility and returns; $exrvol_{t-1}$ and $Rexr_{t-1}$ are the one-period lagged volatility in the exchange rate and returns; ε_{oprvol}, ε_{exrvol}, ε_{Ropr}, ε_{Rexr} are structural shocks. We also estimated the GARCH model which is as specified in equation (7):

$$\sigma_t^2 = s + \sum_{i}^{p} \partial_i \varepsilon_{t-i}^2 + \sum_{j}^{q} \beta_j \sigma_{t-j}^2 \quad (7)$$

where: p is the autoregressive term, while q is the term for the moving average. Volatility was represented by variance given by σ_{t-j}^2. The ARCH effect term, ∂_i functions as the coefficient of residual obtained from the rate of exchange mean equation, β_j is a representation of the GARCH effect. Alternative estimation methods that can be used in this study include Granger causality model analysis, wavelet-based analysis or frequency domain analysis, quantile regression method, predictive regression analysis, CoVaRs model estimator, CCC-GARCH estimator, and time-varying VAR methods. Conversely, we choose the Markov-switching regression modeling (MSRM) according to the works of Hamilton (1989) to calculate the probabilities of transiting from a particular regime to another. In this study, the two regimes identified are, the *flexible* and the *fixed exchange rates* regimes. Accordingly, the MSRM is specified thus:

$$exrvol_t = \begin{cases} d_1 + \sum_{i=1}^{p} \alpha_{i,1}\, exrvol_{t-1} + v_{1t}, & if\, g_t = 1 \\ d_2 + \sum_{i=1}^{p} \alpha_{i,2}\, exrvol_{t-1} + v_{2t}, & if\, g_t = 2 \end{cases} \qquad oprvol_t = \begin{cases} s_1 + \sum_{i=1}^{p} \gamma_{i,1}\, oprvol_{t-1} + v_{1t}, & if\, g_t = 1 \\ s_2 + \sum_{i=1}^{p} \gamma_{i,2}\, oprvol_{t-1} + v_{2t}, & if\, g_t = 2 \end{cases} \quad (8)$$

For volatility in the crude oil market, the MSRM becomes:

$$Rexr_t = \begin{cases} h_1 + \sum_{i=1}^{p} \varphi_{i,1}\, Rexr_{t-1} + v_{1t}, & if\, f_t = 1 \\ h_2 + \sum_{i=1}^{p} \varphi_{i,2}\, Rexr_{t-1} + v_{2t}, & if\, f_t = 2 \end{cases} \qquad Ropr_t = \begin{cases} q_1 + \sum_{i=1}^{p} \phi_{i,1}\, Ropr_{t-1} + v_{1t}, & if\, f_t = 1 \\ q_2 + \sum_{i=1}^{p} \phi_{i,2}\, Ropr_{t-1} + v_{2t}, & if\, f_t = 2 \end{cases} \quad (9)$$

where: d_i, s_i, h_i and q_i denote regimes, namely, *regime 1* and *regime 2*, and are the first-order Markov chain with transition probabilities, and are the coefficients of volatility in exchange rates and exchange rate returns at different regimes; γ_i and ϕ_i are the coefficients of oil market volatility and oil market returns at *regime 1* or *2* respectively. The transition probability matrix is given as:

$$P_r = \begin{bmatrix} l_{11} & 1 - l_{22} \\ 1 - l_{11} & l_{22} \end{bmatrix} \quad (10)$$

where:

$$l_{11} = Pr(g_t = 2/g_{t-1} = 1)$$

$$l_{22} = Pr(g_t = 1/g_{t-2} = 2)$$

$$l_1 = \frac{(1 - l_{22})}{(2 - l_{11} - l_{22})}$$

$$l_1 = \frac{(1 - l_{22})}{(2 - l_{11} - l_{22})}$$

Transition probabilities are denoted as l_{ii} which lies in the unit interval given by $0 < l_{ii} < 1$ while l_i are the steady-state probabilities. Daily data series were utilized from January 1, 1990, through to December 31, 2022, for twenty-one countries (Mauritius, Nigeria, Kenya, Morocco, Ghana, Egypt, South Africa, Uganda, Tanzania, Mali, Burkina Faso, Burundi, Cote d'Ivoire, Mauritania, the Benin Republic, Senegal, Rwanda, Ethiopia, the Congo Republic, Cameroon, and Gabon). We opted for daily data because governments, banks, companies businesses and individuals exporting and importing, international investors, and arbitrageurs, are all engaged in daily currency trading. The Brent crude oil price in USD was utilized. We made use of the everyday Brent crude oil prices because according to Umar et al. (2021), two-thirds of international crude oil contracts are based on Brent oil. After all, it is extensively used. While daily data on oil prices were sourced from the website of International Energy Outlook (https://www.eia.gov), data on nominal exchange rates were sourced from the World Bank database. The Oil Volatility Index (OVX) was sourced from the website of the Chicago Board of Exchange (https://www.cnbc.com/quotes/.OVX). The exchange rate is the local currency per one unit of the USD so a rise in the nominal exchange rate is an indication of devaluation while a fall implies an appreciation of the local currency. Exchange rate returns are gains made on currency trading. These returns were calculated as the percentage change in the exchange value of a given currency. Crude oil market returns are the percentage change in oil market investment.

4. RESEARCH RESULTS

Descriptive information on variables in the relevant nations is provided in Table 1 below. The average, the lowest, the maximum, the standard deviation, and the kurtosis of the periods for the nations looked at. Uganda has the most devalued currency with an exchange rate of Uganda shilling to US dollar (UGX/USD) 0.00063. Ghana had the highest value of a local currency when compared with others. Kurtosis values show that thirteen countries have exchange rates with platykurtic distributions ($k < 3$) while the others have leptokurtic distributions ($k > 3$).

Table 1. Descriptive statistics analysis

Variable	*Mean*	*Min*	*Max*	*Std. dev*	*Kurtosis*
Burkina Faso	0.00205	0.001283	0.004197	0.0006	2.420532
Burundi	0.00174	0.000498	0.006204	0.0019	0.469519
Cameroon	0.00205	0.001283	0.004197	0.0006	2.42053
Congo Republic	0.00205	0.001283	0.004197	0.0006	2.420532
Côte d'Ivoire	0.00205	0.001283	0.004197	0.0006	2.420532
Egypt	0.21007	0.053405	0.909091	0.1286	11.76882
Ethiopia	0.13003	0.020633	0.483092	0.1182	4.058598
Gabon	0.00205	0.001283	0.004197	0.0006	2.420532
Ghana	4.66982	0.166497	32.68	7.9632	3.718809
Kenya	0.01538	0.008839	0.045989	0.0077	5.105612
Mali	0.00205	0.001283	0.004197	0.0006	2.420532
Mauritania	0.04982	0.02649	0.134608	0.0279	1.718759
Mauritius	0.03907	0.022973	0.070925	0.0122	-0.12183
Morocco	0.11064	0.083556	0.137775	0.0103	-0.04448
Nigeria	0.02208	0.0024	0.1269	0.0293	3.795542
Rwanda	0.00295	0.00099	0.01393	0.0026	4.521746
Senegal	0.00205	0.001283	0.004197	0.0006	2.420532
South Africa	0.16200	0.055368	0.39651	0.0910	0.161784
Tanzania	0.00128	0.000435	0.005184	0.0011	4.125001
Uganda	0.00063	0.000258	0.002667	0.0004	8.280423
Benin Republic	0.00205	0.001283	0.004197	0.0006	2.42053
Combined	**49.587**	**9.82**	**132.72**	**0.000641**	**2.4205**

The cross-section dependence test revealed that there is cross-sectional dependence (CSD) among the countries of study ($p < 0.05$). Only three unit-root tests were taken as accurate for this study (Tables 2 and 3). The Pesaran-Shin (IPS), Augmented Dickey-Fuller (ADF), and Phillip-Perron (PP) tests were accepted because they take cognizance of cross-sectional dependence in panel data when calculating unit roots and do not assume independence of cross-sections. Given the confirmation of the existence of cross-section dependence, the tests reveal the stationarity of variables at first differencing. All variables thus satisfy the stationarity condition.

Table 2. Cross-sectional dependence test results

Methods	*Rexr*	*Ropr*	*exr*	*opr*
Breusch-Pagan LM	14502.95** (0.00)	80430.00** (0.00)	55201.27** (0.00)	88704.00** (0.00)
Pesaran scaled LM	697.4246** (0.00)	3914.335** (0.00)	2557.448** (0.00)	4116.136** (0.00)
Bias-corrected scaled LM	697.3971** (0.00)	3914.308** (0.00)	2557.420** (0.00)	4116.108** (0.00)
Pesaran CD	74.87360** (0.00)	283.6018** (0.00)	226.7917** (0.00)	297.8322** (0.00)

*Note: ** Significance at 0.05.*

Table 3. Results of unit root test

Test	Rexr	Ropr	exr	opr	
	I(0)	I(0)	I(0)	I(0)	I(1)
Im, Pesaran, and Shin W-stat	-38.476*	-3.4755*	-11.095*	-2.3582*	-38.672*
ADF — Fisher Chi-square	1246.64*	1246.64*	384.292*	51.302	1263.14*
PP — Fisher Chi-square	3704.71*	3704.71*	301.538*	51.346	2371.20*

*Note: * Significance at 0.05 level.*

Co-integration results of Table 4 reveal a long-term connection between oil prices and exchange rates ($p < 0.05$).

The Dumitrescu-Hurlin causality test (Table 5) results show that oil price movements have a remarkable causative impact on exchange rate movements and not the other way around. In other words, a unidirectional relation abounds from oil prices to exchange rates.

Table 6 reports the optimal lag length as 1. The FPE, AIC, and SC all revealed that lag 1 is the optimum lag for the analysis of the data series. This was implemented in the course of estimation.

Table 4. Results of the co-integration test

Test	Statistic	Test	Statistic
V-statistic	103.6657*	Rho-statistic	-184.0411*
Rho-statistic	-182.7605*	PP-statistic	-99.13854*
PP-statistic	-90.28016*	ADF-statistic	-88.87813*
ADF-statistic	-83.76328*	Rho-statistic	-184.0411*

*Note: * Significance at 0.05 level.*

Table 5. Dumitrescu-Hurlin causality test results

Null hypothesis	W-stat	Z bar-stat	Prob.
Opr does not have a causative effect on *exr*	19.028***	5.036**	0.000
Exr does not have a causative effect on *opr*	1.210	0.138**	0.784

*Note: **, *** indicates significance at 5% and 1% levels respectively.*

Table 6. VAR lag order selection results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-31357.51	NA	0.033821	7.964828	7.968369	7.966041
1	19298.11	101246.9	8.79e-08*	-4.896027*	-4.878322*	-4.889962
2	20434.41	2270.014	6.61e-08	-5.180549	-5.148680	-5.169632
5	20907.96	502.5680	5.93e-08	-5.288624	-5.214262	-5.263151*
7	21246.74	339.0566	5.49e-08	-5.366537	-5.263847	-5.331360
8	21658.58	820.23423	4.96e-08	-5.4671582	-5.350256	-5.427067

Note: LR — Sequential modified LR test statistic, FRE — Final prediction error, AIC — Akaike's information criterion, SIC — Schwarz information criterion, HQ — Hannan-Quinn information criterion.
** Significance at 0.05 level.*

As illustrated in Figure A.4 (see Appendix), exchange rate returns have a steep negative response to innovations in itself in the short term. In other words, a change in exchange returns in a period will cause an opposite movement in exchange rate returns but this would only last for a short period before returns maintain equilibrium values. However, these returns respond positively and weakly to oil price returns in the short run as well, returning to equilibrium by the third period. Exchange rate returns find weak responses to exchange rates and oil prices. Returns on oil prices respond negatively to its internal dynamics, though in the short run before returning to a place of equilibrium. These returns respond positively and weakly to volatilities in oil prices in the short run as well but move back to equilibrium by the second period. The study finds no response of oil price returns to exchange rates.

Impulse response charts revealed that oil prices respond highly to shocks that emanate from variations within themselves. There is an immediate, but short-term positive response of oil prices to shocks within itself 3 months. The prices stabilize after the third month till the fifth month the prices begin to decline steadily with a lower effect than they initially rose. Oil prices however had a near-zero response to the exchange rates of African countries. Concerning its returns, oil prices first respond positively to shocks from oil price returns, then reverse and begin to take a negative pattern with less intensity than they responded positively initially. Oil prices also respond positively to exchange rate returns, and then stabilize by the third period without returning to equilibrium.

The same result is found in the exchange rate's response to oil prices (see Figure A.5–A.6 in Appendix). However, oil prices do not respond to exchange rates as revealed by the plot equal to the origin of the x-axis. Exchange rates however are found to slightly respond to oil price shocks from the second month. The response increases by the fourth month, then by the seventh month. In other words, oil prices have an influence on exchange rates in gradual successions though not immediately. Regarding returns on oil prices and currency rates, the graph shows similar nature and direction of responses of a very weak positive response. Though, the response of the currency rate to its returns is of a slightly larger magnitude.

The forecast error disintegration (Table 8) contains the explanatory power of structural shocks on variables. The 99% explanatory power of exchange rate returns reveals that the variable is highly exogenous as other variables have less than a 1% explanation of returns (*Rex*). The exchange rate also has high exogeneity with over 90% of explanatory power for forecast embedded in itself. Exchange rate returns in the first period hold a 2% power for the prediction of exchange rates, but this falls in the second period to 1.79% and slowly rises. Oil price return also displays a high level of exogeneity as it holds a large predictive ability in explaining variations within itself (> 90%). Initially, variations in exchange rate returns had a higher explanatory power than oil prices. However, by the second period, a trade-off begins between both variables causing the explanatory power of oil prices to rise and that of exchange returns to fall. Oil prices take a different pattern revealing endogeneity with its largest explanatory variable being oil price returns, before itself and finally, returns on exchange rates. The explanatory power of oil price returns however falls as periods extend while that of oil prices rises increasing the autoregressive effect.

Table 7. Structural decomposition

Period	*S.E.*	*Shock1*	*Shock2*	*Shock3*	*Shock4*
Variance decomposition of Rexr					
1	0.034717	100	0	0	0
2	0.034782	99.73729	0.168728	0.020043	0.073936
3	0.034863	99.29899	0.590533	0.029784	0.080696
8	0.034872	99.25675	0.618187	0.043809	0.081251
9	0.034872	99.25657	0.618213	0.043824	0.081389
10	0.034872	99.25638	0.618254	0.043846	0.081525
Variance decomposition of Ropr					
1	0.095745	0.553426	99.44657	0	0
2	0.100115	1.278442	97.78928	0.925509	0.006771
3	0.100473	1.321936	97.46874	1.201444	0.007878
4	0.100621	1.319187	97.47445	1.198505	0.007858
6	0.100672	1.322012	97.42308	1.247052	0.007854
7	0.100703	1.322972	97.39482	1.274354	0.007853
10	0.100806	1.327046	97.30634	1.358771	0.007845
Variance decomposition of opr					
1	4.520830	1.144316	68.83287	30.02281	0
2	7.728649	1.905430	64.53842	33.55445	0.001698
4	12.16264	2.645322	58.57927	38.77184	0.003571
6	15.26415	2.896954	56.44961	40.64928	0.004152
9	18.62201	3.054254	55.18205	41.75884	0.004861
10	19.51606	3.083415	54.94481	41.96668	0.005099
Variance decomposition of exr					
1	0.035084	2.004238	0.000158	0.012571	97.98303
2	0.057807	1.789148	0.011035	0.035429	98.16439
3	0.075756	1.808021	0.027745	0.049923	98.11431
7	0.123059	1.878714	0.052980	0.062935	98.00537
8	0.131590	1.887430	0.056856	0.062585	97.99313
10	0.146422	1.901517	0.064116	0.060651	97.97372

Note: S.E. — Standard error.

GARCH analysis. Each of the cross-sections was tested for the presence of ARCH effects. The oil prices had ARCH effects implying volatility clustering. Exchange rates for Ghana, Kenya, Mauritius, and Tanzania also possessed volatility clustering.

Table 8. Heteroscedasticity tests

Country	*Variable*	*Stat. value*	*P-value*	*Variable*	*Stat. value*	*P-value*
	opr	*106.8162*	*(0.00)*	*Ropr*	*22.241*	*(0.00)*
Burkina Faso	*exr*	0.005967	(0.94)	*Rexr*	0.020988	(0.88)
Burundi	*exr*	0.519727	(0.47)	*Rexr*	3.113719	(0.08)
Cameroon	*exr*	0.005967	(0.94)	*Rexr*	0.020988	(0.80)
Benin Republic	*exr*	0.014263	(0.50)	*Rexr*	0.010328	(0.89)
Congo Republic	*exr*	0.010263	(0.60)	*Rexr*	0.050218	(0.48)
Cote d'Ivoire	*exr*	0.011263	(0.60)	*Rexr*	0.040128	(0.38)
Egypt	*exr*	0.011095	(0.92)	*Rexr*	0.006341	(0.94)
Ethiopia	*exr*	0.027497	(0.87)	*Rexr*	0.005965	(0.94)
Gabon	*exr*	0.015263	(0.90)	*Rexr*	0.020988	(0.88)
Ghana	*exr*	81.333**	(0.00)	*Rexr*	56.008**	(0.00)
Kenya	*exr*	34.922**	(0.00)	*Rexr*	81.137**	(0.00)
Mali	*exr*	0.015263	(0.90)	*Rexr*	0.020988	(0.88)
Mauritania	*exr*	0.019657	(0.89)	*Rexr*	0.033504	(0.85)
Mauritius	*exr*	7.0134**	(0.01)	*Rexr*	16.181**	(0.00)
Morocco	*exr*	0.580195	(0.45)	*Rexr*	0.856612	(0.35)
Nigeria	*exr*	1.680857	(0.19)	*Rexr*	0.06958	(0.17)
Rwanda	*exr*	0.002372	(0.96)	*Rexr*	0.001417	(0.97)
Senegal	*exr*	0.015263	(0.90)	*Rexr*	0.020988	(0.88)
South Africa	*exr*	9.0683**	(0.00)	*Rexr*	9.1398**	(0.00)
Tanzania	*exr*	4.0924**	(0.01)	*Rexr*	4.0374**	(0.02)
Uganda	*exr*	3.67679	(0.06)	*Rexr*	1.463877	(0.23)

*Note: ** Significance at 0.05 level.*

ARCH effects were found for oil price volatilities and oil price returns. For volatilities in exchange rates and exchange rate returns, ARCH effects were present in Ghana, Kenya, Mauritius, South Africa, and Tanzania. As shown in Table 9, the mean equation for oil price returns has all significant coefficients. GARCH term for oil price returns is negative and weakens symmetrical effects. Since the sum of ARCH and GARCH terms is less than 1, this limits our assertion that volatility persistence exists in oil price returns. The result shows weak persistence of volatility shocks. It implies that current shocks of oil prices jointly do not remain in forecasts of variance for long periods into the future. Overall, study models are parsimonious with the least arch terms used.

For the oil price itself, the values show volatility though persistence is not found as the persistence value is greater than 1 (1.0575). It implies that the past values of the variable have a very strong predictive ability on the current values of the variable by the coefficient. Figures A.5 and A.6 show volatility trends of oil prices and returns respectively.

GARCH results for exchange rate volatility are reported in Table 10 below. The constant of the mean equation revealed the conditional mean of exchange rate returns for each of the panels. The one-period lagged value of returns was also found to be significant in the mean equations, except for Mauritius. The immediate past average value for the exchange rate has a predictable ability to determine the current average value. AR(1) parameters and moving averages were only significant in Ghana. ARCH and GARCH terms were also found to be positive and significant in all considered countries. Only Kenya and Mauritius had their exchange rates maintaining volatility persistence as the sum of ARCH and GARCH terms exceeded 1.

Table 9. GARCH estimates for returns on oil prices and oil price volatility

Variable	*Ropr*	*Opr*
C	0.0204** (2.6134) 0.00	0.1550 (0.783) 0.43
R(-1)	-0.6448** (-3.970) 0.00	0.9935** (176.11) 0.00
AR(1)	0.0989** (80.1682) 0.00	-0.2985 (-1.8758) 0.06
MA(1)	0.7354** (5.4259) 0.00	0.5848** (4.635) 0.00
Constant_variance	0.0057** (6.932) 0.00	0.0503 (0.773) 0.43
ARCH term	0.5372** (6.9324) 0.00	0.3060** (4.115) 0.00
GARCH term	-0.1473** (7.6281) 0.00	0.7515** (13.19) 0.00
Persistence	0.3899	1.0575
Likelihood	400.07	-1012.11
AIC	-2.063	5.335
Autocorrelation	> 0.05	> 0.05
Heteroscedasticity	0.6872 0.40	0.1339 0.71

*Note: * Significance at 0.05 level.*

Table 10. GARCH estimates for exchange rate volatility

Variables	*Ghana*	*Kenya*	*Mauritius*	*South Africa*	*Tanzania*
C	0.0007** (2.762) 0.00	0.6636 (1.738) 0.08	0.0964 (0.701) 0.48	0.0140 (0.598) 0.54	0.000004** (14.421) 0.00
R(-1)	1.0013** (1278.7) 0.00	0.9935** (197.05) 0.00	0.9993** (0.7013) 0.48	1.0003** (200.00) 0.00	0.9889** (1452.58) 0.00
AR(1)	0.8660** (25.745) 0.00	-0.2985 (0.049) 0.96	0.2798 (0.785) 0.43	0.4364 (0.783) 0.43	0.0172 (0.012) 0.99
MA(1)	-0.5260** (-7.520) 0.00	0.1987 (0.563) 0.57	-0.0940 (-0.2473) 0.80	-0.3485 (-0.604) 0.54	0.0116 (0.008) 0.99
Constant_variance	0.000000005 (0.288) 0.77	0.0547 (7.156) 0.43	0.0601** (6.345) 0.00	0.0013** (4.588) 0.00	2.09E-14 (1.5733) 0.11
ARCH term	0.5773** (12.576) 0.00	0.5884** (5.647) 0.00	0.5276** (5.672) 0.00	0.3694** (6.100) 0.00	0.5417** (19.11) 0.00
GARCH term	0.7230** (53.93) 0.00	0.5054** (9.099) 0.00	0.6513** (14.216) 0.00	0.7218** (20.219) 0.00	0.6754** (79.34) 0.00
Persistence	1.3003	0.8938	0.8790	1.0913	1.217
Likelihood	1187.45	-708.53	-336.28	-83.21	3700.77
AIC	-6.180	3.746	1.797	0.472	-19.339
Autocorrelation	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05
Heteroscedasticity	0.0532 0.81	0.6145 0.43	0.3210 0.57	0.0621 0.80	0.1670 0.68

*Note: ** Significance at 0.05 level.*

Table 11 shows estimates of exchange rate returns. Volatility persistence is evident in the exchange rate returns of Kenya and Mauritius. There are similar peaks following one another implying that forecasting the exchange rates of both countries will be more feasible and accurate than forecasting exchange rates for the other countries with volatility but weak persistence.

The constant of the mean equation revealed the conditional mean of exchange rate returns for each of the panels. The one-period lagged value of returns was also found to be significant in the mean equations, except for South Africa. AR(1) parameters and moving averages were significant in the estimations of Tanzania and Mauritius. ARCH and GARCH terms were also found to be positive and significant in all considered countries. Summing up ARCH and GARCH terms, answers were less than but close to 1 for all countries estimated except for Kenya. This indicates that volatility shocks in exchange rate returns are persistent in the four countries. Convergence was achieved after 24 iterations. The mean equation shows positive coefficients.

Table 11. GARCH estimates for exchange rate returns

Variables	*Ghana*	*Kenya*	*Mauritius*	*South Africa*	*Tanzania*
C	0.0007 (1.738) 0.08	0.0005 (0.9296) 0.35	-0.0005** (-2.051) 0.04	-0.0037 (-1.5133) 0.13	-0.0007 (-0.473) 0.63
R(-1)	0.9937** (197.05) 0.00	0.1795** (2.803) 0.00	0.8030** (8.4514) 0.00	0.2759 (0.8506) 0.39	0.8364** (2.449) 0.01
AR(1)	0.0171 (0.049) 0.96		0.3194** (2.667) 0.00	-0.2840 (-0.629) 0.52	0.2691** (4.881) 0.00
MA(1)	0.1987 (0.5633) 0.57		0.0612** (-26.35) 0.00	0.0612 (0.0823) 0.93	-0.8349** (-2.443) 0.01
Constant_variance	0.5479 (7.156) 0.77	0.00001** (3.835) 0.00	0.00014** (3.661) 0.00	0.00014** (3.661) 0.00	0.00004** (10.957) 0.00
ARCH term	0.3884** (5.647) 0.00	0.6019** (6.966) 0.00	0.227663** (5.672) 0.00	0.237** (4.003) 0.00	0.1497** (10.479) 0.00
GARCH term	0.5045** (9.099) 0.00	0.6345** (19.212) 0.00	0.651340** (14.216) 0.00	0.6982** (10.334) 0.00	0.5997** (28.235) 0.00
Persistence	0.8929	1.2364	0.879003	0.9352	0.7494
Likelihood	-708.53	909.53	910.95	703.80	966.54
AIC	3.746	-4.735	-4.745	-3.6577	-5.0369
Autocorrelation	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05
Heteroscedasticity	0.06144 0.43	0.0008 0.97	0.1182 0.73	0.0939 0.75	0.6744 0.41

*Note: ** Significance at 0.05 level.*

The constant values represent the average returns got from oil prices and exchange rates respectively. In countries where lagged values are significant ($p < 0.05$), it implies that the past values of the variable have a very strong predictive ability on the current values of the variable by the coefficient. For the variance equation, both ARCH and GARCH terms are positive and less than 1 individually. However, all countries have the sum of both terms greater than 1 weakening stability condition. The model is parsimonious with the least arch terms used. The findings establish the presence of time-varying volatility of oil prices generally and the exchange rates of a few countries.

Volatility graphs (see Figure A.12–A.16 in Appendix) contain conditional standard deviation plots of each of the five countries. The frequency of the spikes for Kenya especially on the left-hand side (LHS) of the graph reveals volatility was higher in earlier years than in later years. Returns on the currency value of the Ghana cedis (GHS) largely reveal an absence of volatility persistence with a single high spike and smaller spikes scattered around the periods. The Marko-regime switching results are reported in Table 12. *Oprvol* had a significant positive influence on the volatility in the exchange rate at both regimes of the exchange rate. Accordingly, when volatility in oil prices is high, it causes devaluation because the additional local currency was needed to acquire the unchanged unit of USD required to purchase an unchanged magnitude of crude oil at the global market and when such volatility is low, it results in appreciation in the official exchange rate. Oil price volatility negatively impacted exchange rate returns at both the flexible and fixed exchange rate regimes. The impact is significant for both regimes. What this signifies is that rising *oprvol* reduces returns on the official exchange rates of all countries in the study. Our empirical findings support the submissions made by Korley and Giouvris (2022) where it was reported that escalating shocks of oil volatility significantly devalued the exchange rate of all oil-exporting/importing countries whereas, plummeting oil volatility resulted in the appreciation of the local currency of all oil-exporting/importing nations in sub-Saharan Africa. Our findings also agree with the findings of Sanusi and Kapingura (2022) who applied time-varying and regime-switching regression methodologies to study the link between oil price, exchange rate, and the stock market in South Africa. The authors reported that a hike in oil price volatility depreciated the external worth of the South African rand (SAR).

In addition, we found that *exrvol* had a negative insignificant effect on the volatility of oil prices in the flexible exchange rate regime. In the second regime of the fixed exchange rate, volatility in exchange rates insignificantly but positively influenced the *oprvol*. However, volatility in exchange rates positively and considerably influenced crude oil returns in the fixed regime. By implication, volatilities in the official exchange rates do not trigger volatility in the oil market. This could be alluding to the fact that oil prices are exogenously determined. Furthermore, high (low) volatility in the official exchange rates stimulates higher (lower) returns in the oil market. These findings supported the findings of Panpan et al. (2022) who included the threshold variables of oil financialization and structural breaks into the VAR model of the regime-specific dollar-oil relation. In particular, Panpan et al. (2022) reported that a rise in the volatility of the USD exchange rate drives the negative impact of the dollar on oil prices.

In sum, the *oprvol* effect of the volatility in exchange rates is not regime dependent, the impact of volatility in oil prices on returns of currency exchange rates and that of exchange rate volatility on oil market returns are both independent of the foreign exchange rate regime. However, the influence of oil price fluctuations on currency volatility across emerging countries depends significantly on the foreign exchange regime. Aside from the transition probability that the influence of volatility in the exchange rate on oil market volatility would persist in the fixed exchange rate regime that is low given by 0.092, all other probabilities are high for both regimes of exchange rates. This suggests the need to curb variations in the exchange rates of all countries covered by the study. The significant positive coefficients of exchange rates together with high transition probabilities reported are indicative of rising exchange rates which is devaluation or depreciation at the flexible or fixed regimes respectively. This provides a negative influence on oil market performance in terms of returns and prices.

Table 12. Markov-regime switching regression results

The dependent variable is exrvol	*Flexible exchange rate regime*		*Fixed exchange rate regime*		*Transition probabilities*
	Coefficient	*p-value*	*Coefficient*	*p-value*	
constant	-0.578	0.010	0.197	0.000	0.8245, 0.5613
oprvol	0.139***	0.000	0.426	0.340	0.5900, 0.6321

The dependent variable is oprvol	*Flexible exchange rate regime*		*Fixed exchange rate regime*		*Transition probabilities*
	Coefficient	*p-value*	*Coefficient*	*p-value*	
constant	1.037	0.109	1.037	0.109	0.623, 0.563
exvol	-0.568	0.230	0.279	0.078	0.925, 0.092

The dependent variable is Rexr	*Flexible exchange rate regime*		*Fixed exchange rate regime*		*Transition probabilities*
	Coefficient	*p-value*	*Coefficient*	*p-value*	
constant	-0.578	0.000	-0.246	0.560	0.509 0.661
oprvol	-0.768***	0.000	-1.059***	0.000	0.671, 0.759

The dependent variable is Ropr	*Flexible exchange rate regime*		*Fixed exchange rate regime*		*Transition probabilities*
	Coefficient	*p-value*	*Coefficient*	*p-value*	
constant	1.079	0.025	1.011	0.000	0.740, 0.463
exrvol	-0.269***	0.000	0.590***	0.000	0.608, 0.958

*Note: *** Significance at 1% level.*

5. CONCLUSION

The paper evaluates the nexus between oil-exchange rate volatilities and returns in 21 African nations based on monthly time series with SVAR and GARCH and the Markov-regime switching model estimators. The empirical Markov-regime switching estimates reveal that the oil price volatility effect of the volatility in exchange rates is not regime dependent, the effect of oil price volatility on exchange rate returns is not regime dependent, and the oil market returns effect of exchange rate volatility is not regime dependent. Only the exchange rate volatility effect of the volatility in oil prices is regime dependent. An analysis of returns revealed that exchange rate returns in Kenya, Ghana, Mauritius, Tanzania, and South Africa have high volatility though persistence is weak in Kenya. Accordingly, exchange rate returns can be predicted from past values. Given that devaluation of currency is popular in these countries, players in the economy may prefer to hold foreign currency with the high predictive power of historical values of these exchange rates.

Oil returns did not show volatility persistence. This can be attributed to the interplay of other economic factors as well as the market interaction of demand and supply in the global oil market. Unlike exchange rates, prices are binding on market participants causing negative returns in periods of glut or abnormal positive returns in global distress periods. Also, oil prices react significantly to shocks in returns. Thus, past oil price returns are a predictor of future oil prices in which higher returns imply that oil prices will reduce in the latter periods from the fourth period after the increase. Oil exporters can forecast increased earnings in subsequent periods when returns are low at a given time. The finding reveals insignificant volatility transmission from exchange rate volatility spill-over to oil prices. In other words, volatility in exchange rates could inconsequentially cause oil prices to move in similar directions by a lower magnitude.

Exchange rate volatility does not influence volatility in oil prices. Rather, results of SVAR show that for studied countries, oil prices do particularly induce appreciation or depreciation of exchange rates. The economic implications of the findings are that oil-producing and exporting countries would have their exchange rates fluctuate slightly due to changing oil prices. Low oil prices would mean less income from exports and this would weaken the exchange rate. Higher oil prices will also elicit the same pattern of exchange rate response. Oil-importing countries will experience the opposite effects having more funds for other macroeconomic investments and this will cause a slight appreciation in exchange rates. However, the response is very minimal. An African nation's volatile exchange rate will not influence oil prices as prices of oil are independent of the economic systems of these developing countries. African economies thus have to be driven by other real sectors and non-oil foreign direct investment (FDI) in the quest for economic growth and achievement of other macroeconomic objectives. Our study has the limitation of not accounting for structural breaks in our model. Hence, future researchers should implement the wavelet-based coherence model that captures threshold variables of structural breaks in the regime-specific link between oil market volatility and exchange rate volatility.

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