Dynamic Interrelationship Between Crude Oil Price Benchmark: A VECM Approach

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Abstract: This study examines the dynamic relationships between major global crude oil price benchmarks – Brent Blend (RCOBRET), West Texas Intermediate (RCOWTI), and Dubai/Oman (RCOD) – in the context of Nigeria's crude oil stock market using a Vector Error Correction Model (VECM). The results show that Brent plays a dominant role in both short-term and long-term price adjustments. The Estimated Error Correction Terms (ECTs) show that deviations from long-term equilibrium are significantly corrected by Brent and, to a lesser extent, by Dubai/Oman. In contrast, the yield on West Texas Intermediate crude oil prices shows limited convergence. The impulse response features and variance degradation indicate that Brent has a major impact on both the returns on crude oil prices in Dubai/Oman and West Texas Intermediate, with West Texas Intermediate being the most reactive to external shocks. The Granger causality test reveals a two-way causal relationship between the return on the crude oil price in Brent and Dubai/Oman, unidirectional causality from the return on the crude oil price in Brent to West Texas Intermediate, and no causal relationship between the return on the crude oil price in West Texas Intermediate and Dubai/Oman and also the model passed dynamic stability tests, confirming the system's robustness.

1. Introduction

Crude oil remains a vital commodity in the global economy, serving as a crucial input in manufacturing and as a financial asset, with its price fluctuations affecting numerous economic pathways. Over recent years, the primary crude oil pricing indicators, such as Brent, WTI, and Dubai, have experienced significant instability, structural changes, and shifting relationships [4]. This shift has created an urgent need to deepen our understanding of the evolving relationships among these pricing indicators. The primary concern is that crude oil pricing indicators no longer operate independently or maintain straightforward linear relationships. In many economies, whether producers or consumers, interactions among various benchmark prices affect decision-making, risk management strategies, and overall economic outcomes [7]; [5]. Nonetheless, existing research frequently examines these benchmarks in isolation or uses static models that fail to capture both short-term fluctuations and long-term equilibrium relationships. For instance, some research has highlighted that crude oil price volatility affects

macroeconomic factors. Still, they seldom explore how various benchmark price series respond to shared disturbances or exhibit integrated relationships. Additionally, significant shifts in the oil market, such as the 2008 financial crisis or regulatory changes, have transformed how these benchmarks relate to one another, underscoring the need for analyses to accommodate evolving dynamics over time [5].

Another concern is that many studies prioritise the impact of crude oil prices on other factors, such as currency exchange rates, stock markets, and economic development, rather than directly modelling the relationships among the various oil price benchmarks. This approach leaves a deficiency in understanding how benchmarks like Brent, WTI, and others move in concert and respond to deviations from long-run equilibrium. Lacking this insight, predictions, risk management techniques, and policy decisions may not be optimal [8]. Multiple motivations thus drive this research. Firstly, given the significant role of crude oil in international trade, energy stability, and financial markets, enhancing our understanding of benchmark interrelations carries substantial implications for market players, policymakers, and scholars. Secondly, in numerous oil-centric economies, the influence of benchmark price fluctuations on domestic factors hinges on the convergence or divergence of these benchmarks; therefore, grasping these dynamics is essential for effective policymaking in both oil-importing and oil-exporting nations [6]. Thirdly, from a methodological perspective, there is an opportunity: using a vector error correction model enables the simultaneous representation of short-term behaviour and adjustments toward long-term equilibria across various nonstationary series. This method is suitable for examining how different oil price benchmarks handle imbalances, respond to shocks, and potentially pass on effects.

By employing a VECM approach, this study aims to expand on previous research in several respects. While many earlier studies utilised VAR, ARDL, GARCH, or SVAR frameworks to investigate the impact of oil prices on macroeconomic variables, few explicitly treat benchmark oil prices as interconnected series within a cointegration framework [4]; [7]; [5]. The VECM facilitates the identification of long-term equilibrium relationships among multiple benchmark price series and allows exploration of how deviations from that equilibrium are rectified over time via the error-correction mechanism. In addition, this research highlights the importance of structural dynamics. By considering possible disruptions to cointegrating relationships, as discussed in Pala [7], and by analysing both short-term adjustment coefficients and impulse responses, we capture more intricate dynamics than mere static regressions provide. Ultimately, by focusing on relationships between benchmarks rather than their downstream influences (for instance, on exchange rates or economic growth), this research adds to the oil price literature from a supply-and-benchmark-market perspective rather than merely from a macroeconomic-outcome perspective. Utilising a VECM framework to analyse the dynamic interactions among crude oil price benchmarks, this study addresses significant deficiencies in understanding how benchmark prices move relative to one another, rectify imbalances, and convey shocks, thereby providing valuable insights for market participants, policymakers, and future studies.

2. Methodology

The data source for this study is the Energy Information Administration website (http://www.eia.gov/dnav/pet/pet_stoc_wstk _dcu_nus_w.htm), and the variables comprise weekly Crude oil Brent (C0B), Crude oil Dubai (COD), and Crude oil WTI (COW) in dollars per Barrel (USD/bbl). It spanned from January 05, 1990, to June 21, 2024 (Total Data Points: 1799)—the statistical software Econometric View (EView) version 10. EView is a powerful statistical software package that enables users to analyse, manage, and produce graphical visualisations of data. The preliminary analysis involves assessing the reliability of the measures, evaluating the analysis's effectiveness, examining the distributions of individual variables, identifying outliers, and ensuring that the data fit the proposed model. Some preliminary analyses include time plots, descriptive statistics, unit root tests for stationarity, ARCH effects, correlation analysis, an unrestricted VAR model, and optimal lag length selection. The Vector Error Correction (VEC) model is a specialised form of the Vector Autoregressive (VAR) model used to integrate the analysed time series data. The VEC model can be expressed as follows:

$$\Delta Y_t = \alpha + \pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-1} + \varepsilon_t$$

- Yt is a vector of the five variables at time t: Yt = [CCPF, CP, GF, MP, OP] (for example, the global macroeconomic variables and commodity prices you are analysing).
- ΔYt is the first difference between the variables (i.e., the variance of the variables).
- α is a constant term (coordinate at the origin).
- Π is the long-run relationship matrix (cointegration matrix). Its rank determines the number of integral equations. It contains information about the long-run equilibrium relationships among variables.
- Γ_i is the short-term dynamics of the system, showing how variables interact in the short run.
- ε_t Represents the error term.

The VEC model is a powerful tool for modelling the interactions between global macroeconomic variables and commodity price fluctuations. By capturing both short-term dynamics and long-term equilibrium relationships, it provides a deep understanding of the impact of global factors on commodity prices, and vice versa, in the context of Nigeria or any other economy with similar characteristics.

3. Results

The time plots in Figures 1, 2, and 3 display the weekly Crude Oil Price in Brent Blend (COBRT), West Texas Intermediate (WTI), and Dubai/Oman. The plots exhibit fluctuations over the years, characterised by high volatility, non-stationarity, seasonality, and cyclical patterns.
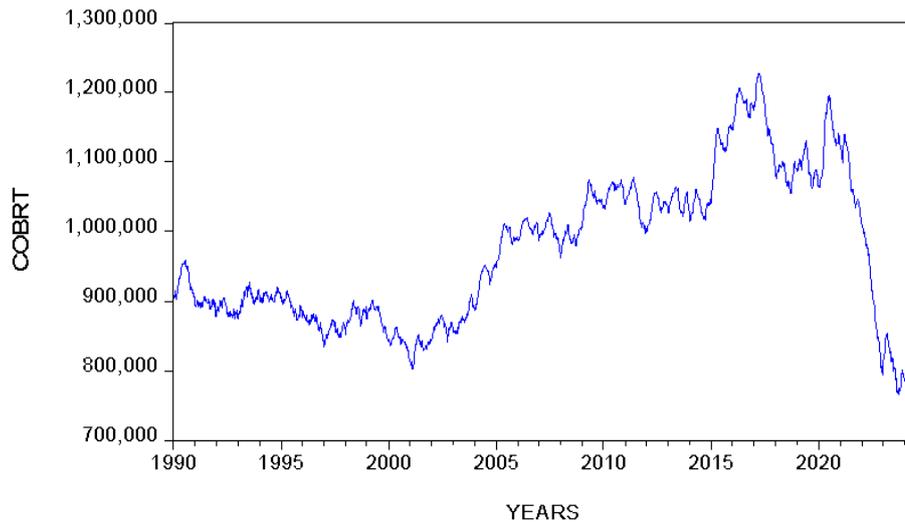

Figure 1: Time plot of weekly crude oil price in Brent blend

These properties suggest that prices are subject to various market and economic forces, creating uncertainty and risk. The fluctuations in prices across the period have significant implications, including price uncertainty, supply-and-demand imbalances, geopolitical influences, and regional differences.
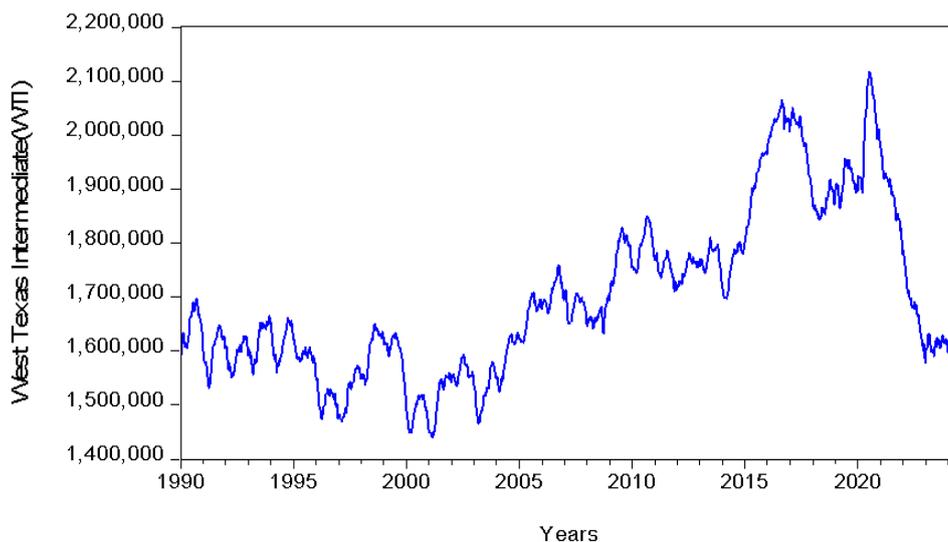

Figure 2: Time plot of the weekly crude oil price in West Texas Intermediate

These observations are supported by various studies and reports on the crude oil market, which highlight the impact of geopolitical events, supply and demand factors, and seasonality on prices.
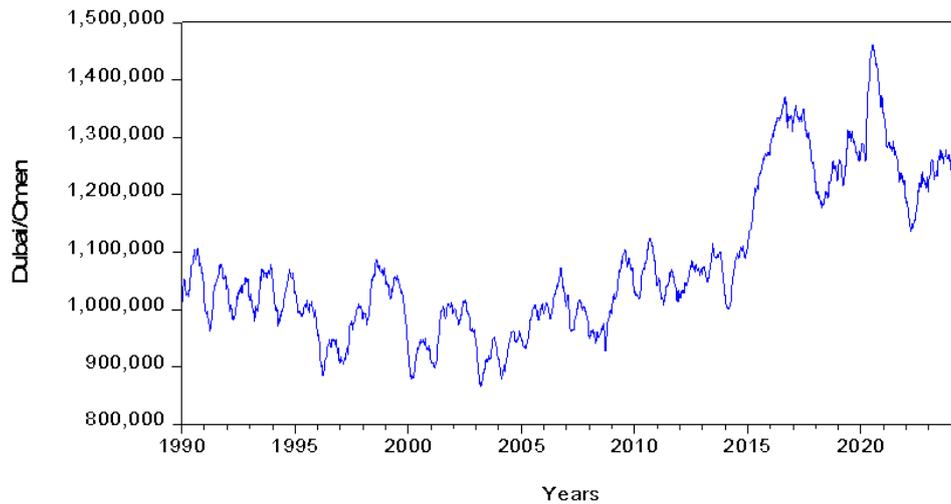
Figure 3: Time plots of weekly crude oil price in Dubai/Oman

The plots suggest that market participants struggle to predict future prices and that regional and global events can significantly affect the market.

Table 1: Descriptive statistics of the raw and returns on stock market prices

Descriptive Statistics of the Dataset	RCOBRT	RWTI	RCOD	COBRT	WTI	COD
Mean	-0.005	0.003	0.014	971	170	108.
Median	0.005	0.014	0.034	961	166	104.
Maximum	2.264	1.710	2.547	123	212.	146.
Minimum	-2.144	-2.058	-3.128	765	144.	866
Std. Dev.	0.481	0.404	0.623	107	153	131
Skewness	0.032	-0.093	-0.105	0.335	0.683	0.792
Kurtosis	3.906	3.840	3.830	2.087	2.654	2.640
Jarque-Bera	61.860	55.488	54.886	96.065	148.923	197.233
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Sum	-8.201	5.169	25.498	1.75E+09	3.06E+09	1.94E+09
Sum Sq. Dev.	416.570	293.028	697.574	2.06E+13	4.23E+13	3.09E+13
Observations	1798	1798	1798	1798	1798	1798

Table 1 presents descriptive statistics for the returns and raw weekly Crude oil Prices in Brent Blend (COBRT), West Texas Intermediate (WTI), and Dubai/Oman. The mean values of the return series indicate that, on average, Brent Blend crude oil returns (RCOBRT) are negative (-0.005), while WTI (RWTI) and Dubai/Oman (RCOD) have small positive mean returns of 0.003 and 0.014, respectively. This suggests that over the observation period, Brent Blend experienced slight declines on average, whereas WTI and Dubai/Oman showed minor appreciation. In contrast, the mean values of the crude oil price series indicate that Brent Blend (COBRT) averaged \$971, WTI (WTI) averaged \$170, and Dubai/Oman (COD) averaged \$108, reflecting significant price differences across the benchmarks. The standard deviation, which measures volatility, shows that Dubai/Oman returns (0.623) exhibit the highest volatility, followed by Brent Blend (0.481) and WTI (0.404). This implies that Dubai/Oman crude oil prices exhibit the greatest volatility, making them less stable than Brent Blend and WTI. Similarly, among the crude oil prices, Brent Blend (107) has the lowest price volatility, while WTI (153) and Dubai/Oman (131) exhibit greater fluctuations.

The skewness values of the return series are close to zero, with RCOBRT (0.032) slightly positive, RWTI (-0.093) slightly negative, and RCOD (-0.105) also negative. This suggests that the distributions of returns are nearly symmetric, with no strong bias toward extreme positive or negative returns. For the crude oil price series, the skewness values are positive (COBRT = 0.335, WTI = 0.683, and COD = 0.792), indicating a slight rightward skew, with prices tending to experience more frequent small increases than decreases. Kurtosis values for the return series (RCOBRT = 3.906, RWTI = 3.840, and RCOD = 3.830)

are slightly above 3, indicating a mild presence of excess kurtosis. This suggests that the return distributions have heavier tails than a normal distribution, meaning extreme price movements (both gains and losses) occur more frequently than would be expected under normality. The crude oil price series, however, exhibits lower kurtosis values (COBRT = 2.087, WTI = 2.654, and COD = 2.640), indicating distributions closer to normal, with a lower likelihood of extreme price fluctuations. The Jarque-Bera statistics for all series are significantly high, with p-values of 0.000, indicating strong rejection of the Null hypothesis of normality.

This confirms that the return series does not follow a normal distribution, with implications for risk modelling and forecasting, since extreme price movements occur more frequently than predicted by standard normal-based models. The lack of normality suggests that financial models that rely on normality assumptions may not adequately capture crude oil returns' behaviour and should be adjusted accordingly. Therefore, the return series for crude oil exhibits mild negative and positive trends, with Dubai/Oman returns showing the highest volatility. The return distributions are nearly symmetric but exhibit slight excess kurtosis, leading to a higher frequency of extreme price movements. The strong rejection of normality suggests that more advanced econometric techniques, such as GARCH models or heavy-tailed distributions, may be more appropriate, as suggested by studies such as Kilian and Park [3]. GARCH models may be necessary for accurate volatility modelling and risk management. However, crude oil price series display greater stability in their distributions, though they still exhibit some rightward skew.

Table 2: Correlation analysis of the raw and returns on stock market prices

Probability	RCOBRT	RWTI	RCOD	COBRT	WTI	COD
RCOBRT	1.000					
RWTI	0.554 (0.000)	1.000				
RCOD	0.517 (0.000)	0.985 (0.000)	1.000			
COBRT	0.030 (0.197)	0.042 (0.078)	0.046 (0.054)	1.000		
WTI	-0.0203 (0.390)	0.0189 (0.424)	0.033 (0.179)	0.935 (0.000)	1.000	
COD	-0.057 (0.015)	0.005 (0.828)	0.037 (0.118)	0.613 (0.000)	0.838 (0.000)	1.000

Table 2 contains the correlation analysis of the raw and returns on stock market prices. The correlation analysis provides insight into the relationship between crude oil returns and prices across different benchmarks. The estimated correlation coefficient between Brent Blend returns (RCOBRT) and WTI returns (RWTI) is 0.554, which is statistically significant at the 1% level (p = 0.000). This positive and moderately strong correlation suggests that the returns of these two crude oil benchmarks tend to move together, reflecting their shared market influences, such as global supply and demand dynamics. The correlation between Dubai/Oman returns (RCOD) and both Brent Blend (0.517) and WTI (0.985) is also statistically significant, further confirming a strong co-movement among crude oil markets. The extremely high correlation between WTI and Dubai/Oman returns suggests that price shocks affecting one are likely to impact the other, aligning with previous studies that highlight the integration of global crude oil markets. In contrast, the correlation between crude oil returns and raw crude oil prices is relatively weak. The correlation between Brent Blend returns and Brent Blend price (COBRT) is only 0.030. It is statistically insignificant (p = 0.197), indicating that fluctuations in weekly Brent Blend returns do not exhibit a strong linear relationship with the absolute price level. Similarly, WTI returns and WTI price (WTI) have an insignificant correlation of -0.0203 (p = 0.390), while Dubai/Oman returns and its price (COD) exhibit a weak but statistically significant negative correlation (-0.057, p = 0.015).

This negative relationship may suggest that as oil prices rise, returns become less volatile or exhibit mean reversion. Such findings are consistent with earlier research showing that oil returns are weakly correlated with price levels due to nonlinear dynamics and external market shocks. The correlations between crude oil prices themselves are strong. The Brent Blend and WTI prices exhibit a very strong positive correlation of 0.935 (p = 0.000), suggesting that the two benchmarks move closely together, likely due to their substitutability in the global oil market. Similarly, Dubai/Oman crude price correlates significantly with both WTI (0.838, p = 0.000) and Brent Blend (0.613, p = 0.000), though the relationship with Brent Blend is comparatively weaker. These findings align with previous studies indicating that Brent and WTI prices are more tightly linked, given their roles as global benchmarks. At the same time, Dubai/Oman is more influenced by regional market conditions. The correlation results confirm that crude oil return series are highly interdependent, with strong relationships particularly between WTI and Dubai/Oman returns. However, the weak correlation between crude oil returns and raw price levels suggests that price trends alone are insufficient indicators of return behaviour. The strong correlations among crude oil price benchmarks reaffirm the global integration of oil markets, with Brent and WTI exhibiting a tighter connection than Dubai/Oman. These findings emphasise the need for dynamic models that account for the complex interactions among crude oil markets rather than relying solely on price-based predictions.

Table 3: Unit root tests of the raw on stock market prices

Variable	t-Statistic	P-Value	Remarks
COBRT	-1.428	0.570	1(1)
△ (COBRT)	-14.835	0.000	
COD	-1.886	0.339	1(1)
△ (COD)	-13.276	0.000	
WTI	-1.523	0.522	1(1)
△ (WTI)	-15.633	0.000	

Note: △ Differenced

Table 3 shows the unit root tests of the raw on the stock market prices of Crude oil. The unit root test results assess the stationarity of crude oil prices (COBRT, COD, and WTI) using their t-statistics and p-values. The Null hypothesis of the unit root test assumes that the series is nonstationary. Suppose the absolute value of the t-statistic is lower than the critical value and the p-value is greater than 0.05. In that case, the Null hypothesis cannot be rejected, indicating that the series has a unit root and is nonstationary (Figure 4).
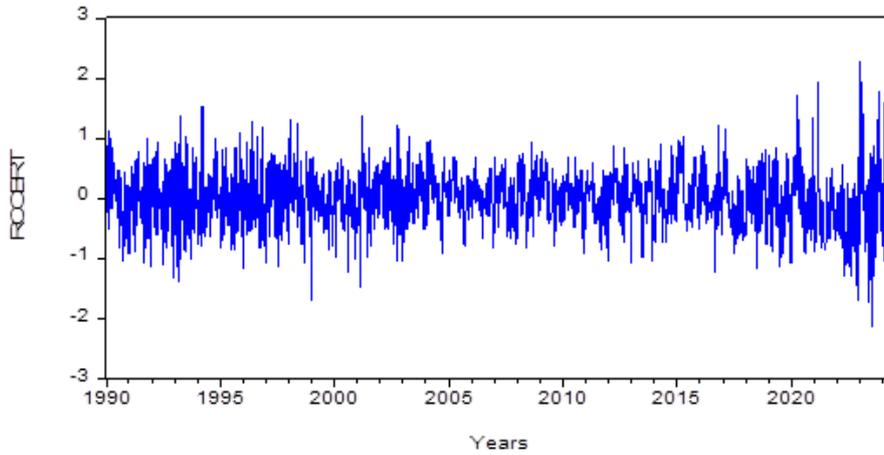

Figure 4: Time plot of returns on weekly crude oil price in Brent Blend (COBRT)

For the crude oil price variables, COBRT, COD, and WTI, the t-statistics are -1.428, -1.886, and -1.523, respectively, with corresponding p-values of 0.570, 0.339, and 0.522. Since all p-values are greater than 0.05, the results confirm that these crude oil price series are nonstationary at their levels. However, after first differencing ($\triangle$), the test statistics become highly negative: -14.835 for COBRT, -13.276 for COD, and -15.633 for WTI, all with p-values of 0.000 (Figure 5).
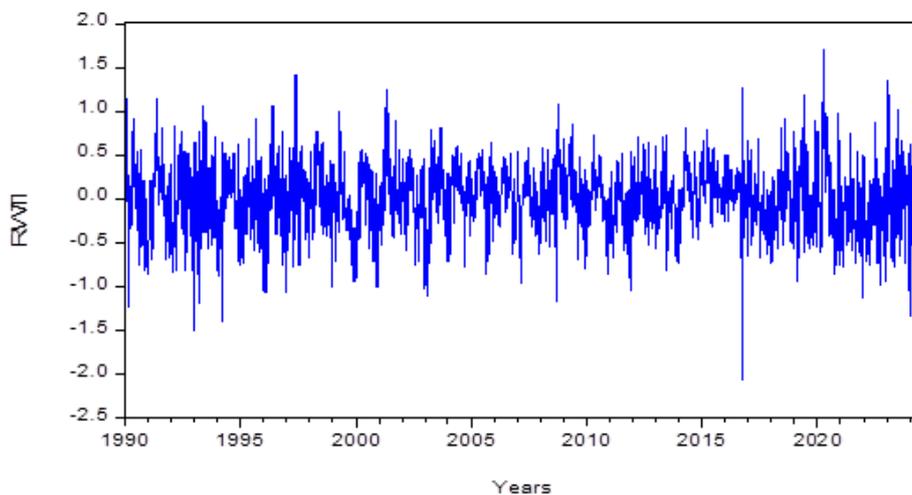

Figure 5: Time plot of returns on weekly West Texas Intermediate (WTI)

These values indicate strong evidence against the null hypothesis, confirming that the first differences of the series are stationary. These results imply that crude oil prices follow a unit root process and are integrated of order one, I (1). This means that stochastic trends characterise their long-term behaviour, and any shocks to the series will have permanent effects rather than reverting to a mean. Consequently, any econometric modelling of this price series should account for its non-stationarity by applying first-differencing or cointegration techniques to avoid spurious regressions. These findings are consistent with previous studies on crude oil prices, which generally conclude that oil prices are nonstationary and follow a random walk process (Figure 6).
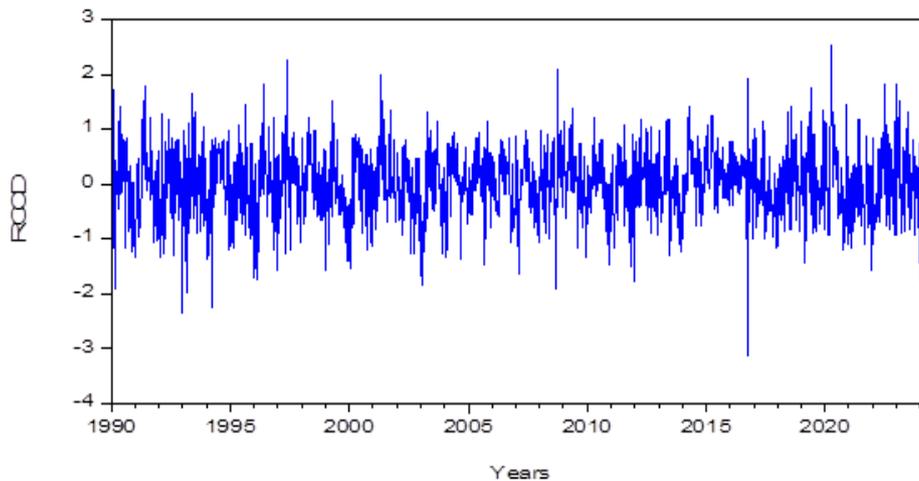

Figure 6: Time plots of returns on weekly crude oil price in Dubai/Oman (COD)

The time-series plots of returns for Brent Blend (COBRT), West Texas Intermediate (WTI), and Dubai/Oman (COD) in Figures 4, 5, and 6 provide insights into the volatility and trends in crude oil prices. In Figure 4, the time plot of Brent Blend crude oil price returns (COBRT) exhibits high-frequency fluctuations around a mean close to zero, suggesting volatility clustering. Periods of relatively low volatility are followed by sudden spikes in return variations, indicating the presence of shocks or external events affecting crude oil prices. This behaviour is typical of a financial time series and aligns with findings in energy economics, where crude oil returns are known to exhibit time-dependent volatility. Figure 5, which represents the time plot for WTI returns, follows a similar pattern, with frequent swings between positive and negative returns. However, the magnitude of fluctuations varies over time, reinforcing the idea that external market forces, such as supply-demand shocks, geopolitical events, and macroeconomic factors, influence WTI prices.

The presence of periods of heightened volatility followed by calmer periods is a key characteristic of crude oil returns. In Figure 6, the time plot of Dubai/Oman crude oil price returns (COD) shows comparable volatility clustering, indicating that price movements are not random but are influenced by global crude oil market conditions. The presence of sharp peaks and troughs suggests sudden price shocks, possibly driven by OPEC decisions, economic downturns, or market speculation. The time plots confirm that crude oil price returns are highly volatile and exhibit features consistent with financial time series, including periods of turbulence followed by relative stability. These findings align with previous studies, such as those by Li et al. [6], which highlight that crude oil markets are subject to price shocks and nonstationary volatility. The observed fluctuations imply that any predictive modelling or risk management strategies should account for volatility clustering, structural breaks, and external shocks affecting the global oil market (Table 4).

Table 4: Test for cointegration of stock market prices

Unrestricted Cointegration Rank Test (Trace)					Unrestricted Cointegration Rank Test (Maximum Eigenvalue)			
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**	Eigen Value	Max-Eigen Statistic	0.05 Critical Value	Prob.**
r=0	0.126	458.606	29.797	0.000	0.126	241.495	21.132	0.000
r≤1	0.089	217.111	15.495	0.000	0.089	166.983	14.265	0.000
r≤2	0.028	50.129	3.841	0.000	0.028	50.129	3.841	0.000
r≤3	0.126	458.606	29.797	0.000	0.126	241.495	21.132	0.000

The results of the cointegration test indicate the presence of long-run equilibrium relationships among stock market prices. The Trace test and Maximum Eigenvalue test both reject the Null hypothesis of no cointegration at all levels (r = 0, r ≤ 1, r ≤ 2, and r ≤ 3), as the computed test statistics exceed the respective critical values at the 5% significance level. At r = 0, the trace statistic (458.606) is far greater than the critical value (29.797), with a probability of 0.000, confirming the rejection of the Null hypothesis of no cointegrating equation. Similarly, the maximum eigenvalue statistic (241.495) exceeds the critical value (21.132), further validating the existence of a long-run relationship. This pattern continues for r ≤ 1 and r ≤ 2, reinforcing the robustness of the cointegration findings. The presence of cointegration implies that despite short-term fluctuations, stock market prices move together over time, suggesting a stable equilibrium relationship. This result aligns with prior studies in financial markets, such as Basher et al. [1], which demonstrate that financial and commodity markets often exhibit long-term integration despite short-run volatility. The implications of these findings are significant for investors and policymakers, as they suggest that crude oil stock markets are interdependent in the long run, meaning price movements in one market could influence the other (Table 5).

Table 5: VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
1	601.1954	NA	0.000104	-0.661671	-0.634068	-0.651479
2	728.1239	253.0060	9.08e-05	-0.793435	-0.738228	-0.773050
3	754.5745	52.63511	8.90e-05	-0.812932	-0.730123	-0.782356
4	795.8536	82.00484	8.59e-05	-0.848998	-0.738586*	-0.808229*
5	811.1478	30.33206	8.53e-05	-0.856031	-0.718015	-0.805070
6	813.9090	5.466835	8.59e-05	-0.849060	-0.683441	-0.787907
7	826.4973	24.88129	8.55e-05	-0.853070	-0.659847	-0.781724
8	840.3648	27.36317*	8.51e-05*	-0.858508*	-0.637683	-0.776970
Indicates lag order selected by the criterion.						
LR: sequential modified LR test statistics (each test at 5% level).						
FPE: Final prediction error.						
AIC: Akaike information criterion.						
SC: Schwarz information criterion.						
HQ: Hannan-Quinn information criterion.						

Before conducting the cointegration test, the appropriate lag length for the Vector Autoregression (VAR) model was determined using various criteria. The Sequential modified LR test, FPE, and AIC all suggest that a lag length of four (or three, due to the loss of one length) is the most appropriate for the VECM model specification. The VAR lag-order selection criteria results indicate that the optimal lag length is determined by multiple criteria, including the sequential likelihood ratio (LR) test, Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), and Hannan-Quinn Criterion (HQ). The lowest values of AIC (-0.858508), FPE (8.51e-05), and LR (27.36317) indicate that lag 8 is the most suitable for the model. The SC and HQ criteria, which impose stronger penalties for additional lags, suggest a lower lag selection (lag 4). However, since SIC is preferred in time-series modelling for its balance between model complexity and goodness-of-fit, lag four is chosen as the optimal lag. A longer lag length captures more dynamics in the relationships among variables, particularly in financial and commodity markets, where price movements depend on past values. However, excessive lags can introduce overfitting and reduce the model's forecasting efficiency. Compared to previous studies, this result aligns with financial time-series research, which often identifies longer lags when dealing with volatile, interdependent variables such as crude oil prices and stock markets. The chosen lag order ensures that past shocks in crude oil prices and stock returns are adequately captured in the model's forecasting and policy analysis. These results provide evidence of long-run relationships between the crude oil price benchmarks. This guides the specification of an ECM model to capture these relationships.

Table 6: Results of the error correction model of stock market prices

Variables	Cointegration Rank	ECT	Residuals Heteroscedasticity Test	VEC Residual Normality Tests
RCOBRT	3	-0.507(0.03)	543.658 F (20,000)	42.618 (df=3), (0.000)
RWTI	3	0.658(0.060)	543.658 F (20, 0.415)	40.900(df=3), (0.100)
RCOD	3	-0.821(0.072)	543.658 F (20, 0.000)	42.618 (df=3), (0.000)

Note: The values in parentheses () are degrees of freedom and p-value.

The results in Table 6 are the Error Correction Model (ECM). The Error Correction Model (ECM) equations were estimated. The error correction term (ECT) measures the speed at which stock market prices adjust back to equilibrium after a shock. In this case, the estimated ECT values for Brent Blend crude oil price returns (COBRT) (-0.507, p=0.03), West Texas Intermediate Returns (RWTI), (0.658, p=0.060), and Dubai/Oman crude oil price returns (RCOD) (-0.821, p=0.072) provide insights into the responsiveness of stock market prices to deviations from long-term equilibrium relationships. For RCOBRT, the ECT value of -0.507 is negative and statistically significant at the 5% level (p=0.03), suggesting that about 50.7% of disequilibrium is corrected in the next period. This means that when stock market prices deviate from their long-term trend due to shocks, they adjust relatively quickly back to equilibrium. A higher speed of adjustment indicates stronger long-term relationships among the stock market variables and crude oil prices. For RWTI, the ECT value of 0.658 is positive and not statistically significant (p=0.060), implying that the adjustment process for West Texas Intermediate prices is less reliable. Since a positive ECT suggests divergence rather than convergence, this result indicates that shocks to WTI returns may take longer to correct, or that other factors may delay the adjustment process.

For RCOD, the ECT value of -0.821 is negative but only weakly significant (p=0.072). A negative ECT indicates that about 82.1% of deviations from equilibrium are corrected in the following period, suggesting a rapid adjustment. However, the marginal significance level (p=0.072) indicates that this correction speed is not strongly reliable at the 5% significance threshold, though it may still hold at a 10% level. The residual diagnostics indicate heteroscedasticity in all models (F-statistic: 543.658), suggesting non-constant variance in the residuals and potentially affecting the efficiency of the estimates. The VEC residual normality tests show significant p-values for RCOBRT and RCOD (p=0.000), indicating that the residuals are not normally distributed, which might affect inference and model stability. In contrast, for RWTI, the normality test suggests a better fit (p=0.100), indicating relatively well-behaved residuals in that equation. These results are consistent with previous studies that have found varying speeds of adjustment in oil price-stock market relationships, often depending on market efficiency, economic structure, and regional factors. The significance of the negative ECT for RCOBRT and RCOD aligns with the literature, which suggests that crude oil markets tend to revert to equilibrium aftershocks. However, the WTI adjustment process appears less stable in this case. Also, the Vector Error Correction Model (VECM) estimates include the cointegrating equations (Long-run Relationships) and the Error Correction Model (Short-run Dynamics).

3.1. Cointegrating Equations (Long-Run Relationships)

CoinEQ1: $RCOBRET_{t-1} - 2.026 * RCOWTI_{t-1} + 0.034 = 0$

CoinEQ2: $RCOD_{t-1} + 0.224 * RCOWTI_{t-1} - 0.049 = 0$

This equation suggests a long-term cointegrating relationship between the returns on Brent and WTI crude oil prices. The coefficient -2.026 implies that an increase of 1 unit in WTI is associated with an increase of 2.026 units in Brent over the long term to maintain equilibrium, and the positive constant (0.034) acts as an adjustment offset or intersection indicating the equilibrium level of the system. If this relationship is breached – e.g., Brent becomes too high relative to WTI – the error-correction mechanism (as indicated by the ECM results) will kick in to restore balance. Brent sharply adjusts to restore this ratio (as seen in the significant error correction in Brent crude oil returns). Similarly, CointEq2 shows a long-term relationship between Dubai/Oman and WTI prices. The small positive coefficient for WTI (0.224) indicates that the RCOD tends to move more independently, with only moderate co-movement with WTI, and the constant (-0.049171) again represents an equilibrium shift. The implication is that, compared to Brent, Dubai/Oman shows a weaker link to WTI. This is also reflected in the error-correction conditions: RCOD and RCOWTI do not significantly correct deviations from this equation, suggesting that the second cointegration pathway is weaker and less stable than the first. Overall, CointEq1 (Brent-WTI) captures a stronger, more meaningful economic relationship, likely because it serves as a global crude oil benchmark. At the same time, CointEq2 (Dubai/Oman-WTI) suggests a more regionally nuanced relationship with weaker economic connectivity and less short-term responsiveness. These equations confirm that Brent and WTI are closely linked in the long term, while Dubai/Oman maintains a looser connection with the broader market dynamics that WTI represents. Also, the Error Correction Model (Short-run Dynamics) was estimated, and the results are shown below.

$$\Delta RCOBRET_t = -0.811 * CointEq1 - 1.003 * CointEq2 + 0.252 * \Delta RCOBRET_{t-1} - 0.032 * \Delta RCOBRET_{t-2}$$
$$+ 0.072 * \Delta RCOBRET_{t-3} + 0.050 * \Delta RCOD_{t-1} - 0.027 * \Delta RCOD_{t-2} - 0.355 * \Delta RCOD_{t-3}$$
$$+ 0.067 * \Delta RCOWTI_{t-1} + 0.131 * \Delta RCOWTI_{t-2} + 0.532 * \Delta RCOWTI_{t-3} - 0.002$$

$$\Delta RCOD_t = 0.461 * CointEq1 - 0.107 * CointEq2 + 0.467 * \Delta RCOBRET_{t-1} + 0.134 * \Delta RCOBRET_{t-2}$$
$$+ 0.076 * \Delta RCOBRET_{t-3} + 0.369 * \Delta RCOD_{t-1} - 0.168 * \Delta RCOD_{t-2} - 0.492 * \Delta RCOD_{t-3}$$
$$+ 1.046 * \Delta RCOWTI_{t-1} + 0.301 * \Delta RCOWTI_{t-2} + 1.010 * \Delta RCOWTI_{t-3} + 0.001$$

$$\Delta RCOWTI_t = 0.303 * CointEq1 - 0.053 * CointEq2 - 0.298 * \Delta RCOBRET_{t-1} + 0.086 * \Delta RCOBRET_{t-2}$$
$$- 0.051 * \Delta RCOBRET_{t-3} - 0.318 * \Delta RCOD_{t-1} + 0.095 * \Delta RCOD_{t-2} - 0.335 * \Delta RCOD_{t-3}$$
$$+ 0.798 * \Delta RCOWTI_{t-1} - 0.132 * \Delta RCOWTI_{t-2} + 0.668 * \Delta RCOWTI_{t-3} + 0.002$$

The short-term error corrects equation one shows that Brent reacts strongly and significantly to deviations from long-term equilibrium (both CointEq1 and CointEq2). This confirms that crude oil prices in Brent bounce back to equilibrium, suggesting an important role in the price adjustment mechanism. Own past changes in Brent crude oil prices have a positive influence, especially on lag one. Other variables, such as the previous returns on West Texas Intermediate Crude Oil Prices, also have a positive impact on Brent, especially at layer 3a (a large coefficient of 0.533), indicating that returns on West Texas Intermediate crude oil prices have a strong short-term spillover effect on Brent. The effect of the RCOD is mixed, with a significant negative impact on delay 3. Similarly, the error-correction model for the second equation shows that the return on crude oil prices in Dubai/Oman reacts significantly to CointEq1 but not to CointEq2. This implies some adjustment pressure, but weaker than Brent. Its own past values, which yield crude oil prices in Dubai/Oman, have mostly negative coefficients, indicating a dynamic that returns to the average. Other variables, such as returns on West Texas Intermediate crude oil prices, also have a very strong positive short-term effect on all delays, suggesting that Dubai/Oman reacts to shocks in those returns.

The returns on crude oil prices in Brent's previous changes negatively affect the returns on crude oil prices in Dubai/Oman, especially on lag 1. The third equation for the error correction terms also shows that returns on West Texas Intermediate crude oil prices respond positively to CointEq1, but the response is weaker than that of Brent's. It is marginally involved in long-term adaptation, showing that it follows rather than leads. The returns on West Texas Intermediate crude oil prices exhibit strong dependence on their own lags, especially at layers 1 and 3, indicating that returns are partially self-propelled. Other variables, including both Brent and Dubai/Oman's past values, also have a negative impact, reflecting the interdependence between benchmarks, but Brent's effect is more consistent. All equations have reasonably good R-squared values (about 61% to 66%), demonstrating very high explanatory power. All error-correction terms for CointEq1 are statistically significant, indicating the presence of meaningful long-term relationships. F-statistics support the overall adequacy of the model.

The results of the VECM confirm the existence of two complementary relationships between Brent crude prices, Dubai/Oman, and WTI, with Brent playing a central role in both short-term and long-term adjustments. WTI exerts a strong long-term influence on Brent, while Brent exerts a heavy short-term influence on both Dubai/Oman and WTI. This confirms Brent's dominant role as a global pricing benchmark in the structure of the Nigerian crude oil market. Cholesky's order goes from RCOBRET → RCOD → RCOWTI. The system is stable and exhibits significant long- and short-term connections, especially between Brent and WTI, which is essential for understanding volatility and shock transmission in the Nigerian crude oil market. The results show that Brent crude oil prices are the dominant force in both short- and long-term adjustment. The returns on crude oil prices in Dubai/Oman are also sensitive to changes in West Texas Intermediate returns, but are not heavily involved in error correction. The returns on crude oil prices in the West Texas Intermediate play are more reactive and supportive, influenced by the dynamics of both Brent and Dubai/Oman. The dynamic stability test for the model on Nigerian Crude Oil Stock Market Prices, with benchmarks, is shown in Figure 7 below.
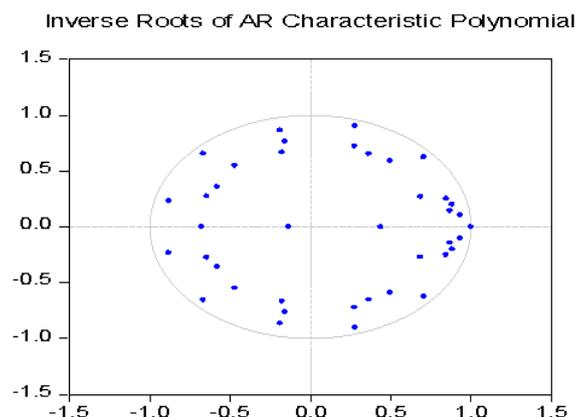

Figure 7: Dynamic stability plot on Nigerian crude oil stock market prices

The results from Figure 7 show dynamic stability plots of Nigeria's crude oil market prices. The dynamic stability plot assesses whether a multivariate time series model, such as a Vector Error Correction Model (VECM), is dynamically stable. The

condition of dynamic stability is that all eigenvalues (or roots) of the companion matrix must lie within the unit circle, which means that they must have moduli (absolute values) less than one. This ensures that shocks to the system die out over time instead of exploding. In this case, the statement confirms that the chart is stable, all points fall within the unit circle, and that the model used to estimate the ratio of crude oil price benchmarks is dynamically stable. This implies that the system of equations detailing the price movements of Brent Blend, West Texas Intermediate, and Dubai/Oman is stable over time. The mean price shocks in one benchmark (e.g., Brent) will not lead to runaway effects in the other benchmarks. The volatility and price movements are well-behaved and mediocre in the long run. The model's forecasts are reliable because the underlying structure is mathematically sound and does not produce nonstationary or explosive results. The stability of the system suggests that crude oil price benchmarks for Nigeria's oil market interact in a dynamically consistent and predictable manner, allowing for meaningful economic interpretation, policy analysis, and forecasting. Also, the pairwise Granger causality tests for Nigerian crude oil stock market prices were estimated, and the results are shown in Table 7.

Table 7: Pairwise Granger causality tests for Nigeria crude oil stock market prices

The null hypothesis is that		F-Statistic	Prob.
RCOD does not Granger-cause RCOBRET	410	4.60685	0.0035
RCOBRET does not Granger-cause RCOD			2.E-05
RCOWTI does not Granger-cause RCOBRET	410	1.96871	0.1181
RCOBRET does not Granger-cause RCOWTI			9.E-08
RCOWTI does not Granger-cause RCOD	410	0.02407	0.9949
RCOD does not Granger-cause RCOWTI			0.1808

The results in Table 7 present the pairwise Granger causality tests for Nigeria's crude oil stock market prices, revealing the directional relationships among the returns of the three crude oil price benchmarks – Brent Blend (RCOBRET), West Texas Intermediate (RCOWTI), and Dubai/Oman (RCOD). Granger causality does not imply true causality but indicates whether past values of one variable help predict another. From Table 7, it is found that the relationship between two variables, as indicated by "→" (RCOD → RCOBRET), shows that the null hypothesis that RCOD does not Granger cause RCOBRET is rejected at the 1% level (F = 4.607, p = 0.004). This means that RCOD has predictive power over RCOBRET. RCOBRET → RCOD: The Null hypothesis is also rejected with a very significant p-value (F = 8.485, p = 0.000), indicating that RCOBRET also Granger-causes RCOD. This two-way causal relationship suggests a strong feedback correlation between Brent and Dubai/Oman prices. RCOWTI → RCOBRET, null hypothesis is not rejected (F = 1.969, p = 0.118), so RCOWTI Granger does not cause RCOBRET. This implies that WTI prices have no predictive power over Brent yields in this context. RCOBRET → RCOWTI: The zero is rejected (F = 12.432, p = 0.000), which means that RCOBRET Granger causes RCOWTI. Brent affects WTI, but not vice versa. RCOWTI → RCOD: null hypothesis is not rejected (F = 0.0241, p = 0.9949), indicating no predictable correlation between WTI and Dubai/Oman. RCOD → RCOWTI shows that the null hypothesis is also not rejected (F = 1.635, p = 0.181), which also indicates no reverse causality. The results show bidirectional Granger causality between Brent and Dubai/Oman, unidirectional causality from Brent to the return on West Texas Intermediate crude oil prices, and no causal relationship between the return on West Texas Intermediate crude oil prices and Dubai/Oman. This implies that Brent plays a key role in the price dynamics of these benchmarks within the Nigerian crude oil exchange context.

Table 8: Impulse response function for Nigerian crude oil stock market prices

Response of RCOBRET			
Period	RCOBRET	RCOD	RCOWTI
1	0.930210	0.000000	0.000000
2	0.455546	-0.040884	0.199724
3	0.046560	-0.093457	0.319568
4	-0.017253	-0.165762	0.321312
5	-0.040975	-0.109816	0.228127
6	-0.026329	-0.029860	0.175730
7	0.024365	-0.002664	0.181222
8	0.073480	0.012791	0.193173
9	0.097765	0.012971	0.196480
10	0.102107	-0.006459	0.198255
Response of RCOD			
Period	RCOBRET	RCOD	RCOWTI
1	0.562503	1.135131	0.000000

Period	RCOBRET	RCOD	RCOWTI
2	0.323560	0.656536	0.011697
3	0.321370	0.085676	-0.081475
4	0.365861	-0.002702	0.007244
5	0.165856	-0.127876	0.043232
6	-0.020970	-0.202715	0.010087
7	-0.114449	-0.137694	0.011983
8	-0.142318	-0.054472	0.004415
9	-0.112129	0.005080	-0.026800
10	-0.055179	0.045950	-0.043184
Response of RCOWTI			
Period	**RCOBRET**	**RCOD**	**RCOWTI**
1	0.390907	0.700307	0.134437
2	0.254188	0.399623	0.157520
3	0.246624	0.042316	0.056257
4	0.266902	-0.019545	0.106179
5	0.144980	-0.098498	0.143331
6	0.030018	-0.142241	0.125510
7	-0.031372	-0.100764	0.121663
8	-0.049833	-0.048776	0.115725
9	-0.029485	-0.010924	0.097797
10	0.007216	0.015101	0.087734
Cholesky Ordering: RCOBRET RCOD RCOWTI.			

The results in Table 8 show the Impulse Response Function (IRF) for Nigeria's crude oil stock market prices, showing how each crude oil price benchmark – Brent (RCOBRET), Dubai/Oman (RCOD), and West Texas Intermediate (RCOWTI) – responds over time (10 periods) to a shock of one unit by itself and in the other variables, based on the Cholesky order: RCOBRET → RCOD → RCOWTI.
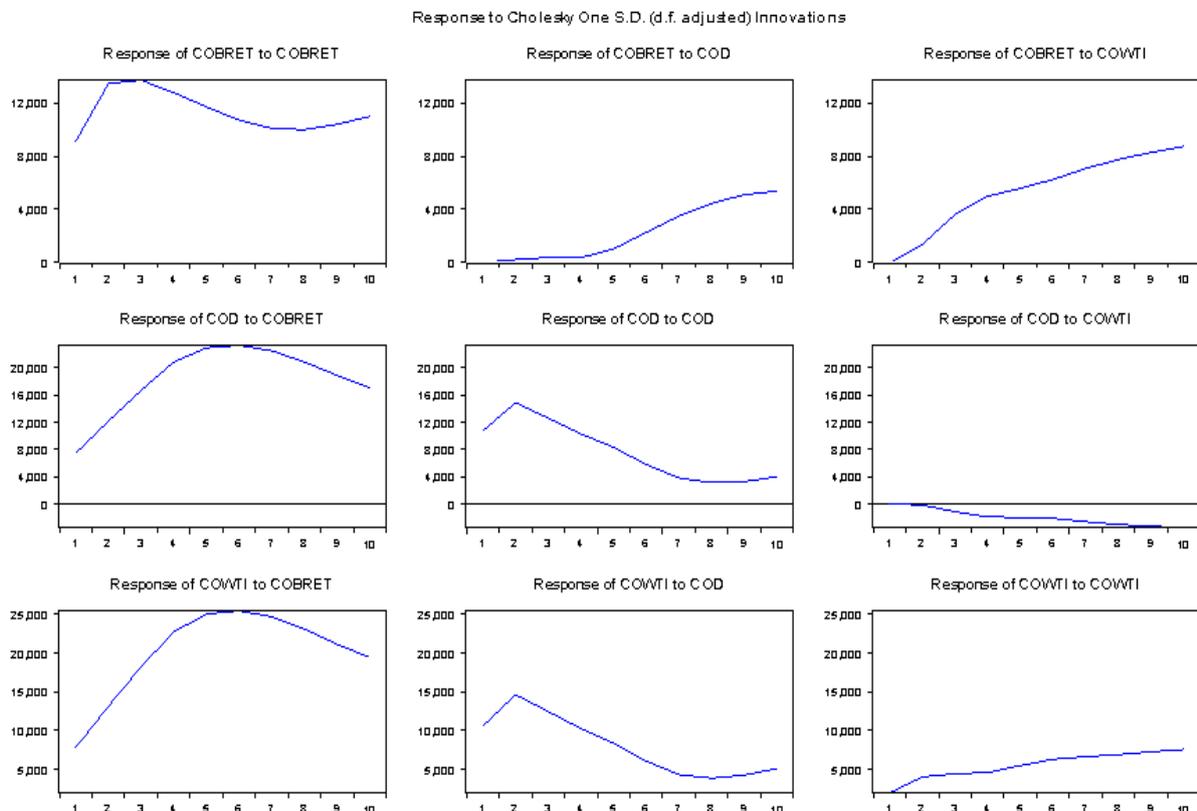

Figure 8: Impulse response function graphs for Nigerian crude oil stock market prices

RCOBRET's impulse response to its own shock starts very strongly at 0.93 in period 1 and gradually decreases, even becoming slightly negative around periods 4 to 6, before recovering slightly towards the end. This indicates that a shock to Brent has a strong immediate effect on its own returns, but the effect dies out and stabilises over time. Meanwhile, the responses to RCOD and RCOWTI are initially zero but gradually increase in magnitude, especially for RCOWTI, which has a consistent positive effect from period 2 onwards, underscoring that Brent returns are increasingly affected by WTI shocks over time. For RCOD, the immediate effect of its own shock is quite large at 1.13 in period 1 but wears off quickly. The reaction to RCOBRET is also significant, starting at 0.56 and remaining notable over several periods, indicating that Brent shocks are having a significant and sustained impact on prices in Dubai/Oman. The response to RCOWTI is relatively small, sometimes positive and sometimes negative, suggesting that WTI plays a limited role in influencing prices in Dubai/Oman. The RCOTTI response shows a modest immediate effect from its own shock (0.13 in period 1), but, interestingly, the effects from RCOBRET (0.39) and RCOD (0.70) are much stronger at first.

Over time, the influence of its own shocks strengthens slightly, while the impact of shocks from Brent and Dubai/Oman decreases but remains remarkable. This suggests that WTI is heavily impacted by external shocks from Brent and Dubai/Oman, especially in the early periods. The results indicate a strong interdependence between the three benchmarks, with Brent playing a dominant role as a shock transmitter. Shocks to Brent affect both the returns on crude oil prices in Dubai/Oman and West Texas Intermediate significantly and sustainably. In contrast, the returns on crude oil prices in Dubai/Oman are less affected by West Texas Intermediate, but still moderately affected by Brent. The yield on West Texas Intermediate crude oil reacts to both Brent and Dubai/Oman shocks but has a limited impact on them. This highlights Brent's leadership role in the global crude oil price system, which shapes market dynamics in Nigeria. The multiple graphs of the impulse response function for Nigeria's crude oil stock market prices are shown in Figure 8. Similarly, the variance decomposition function for Nigerian Crude Oil Stock Market Prices is shown in Table 9.

Table 9: Variance decomposition function for Nigeria crude oil stock market prices

Variance Decomposition of RCOBRET				
Period	S.E.	RCOBRET	RCOD	RCOWTI
1	0.930210	100.0000	0.000000	0.000000
2	1.055639	96.27046	0.149992	3.579544
3	1.107881	87.58199	0.847781	11.57023
4	1.165511	79.15683	2.788732	18.05444
5	1.193397	75.61863	3.506694	20.87468
6	1.206922	73.98084	3.489747	22.52941
7	1.220698	72.36034	3.411903	24.22776
8	1.238137	70.68857	3.327143	25.98429
9	1.257503	69.13250	3.236092	27.63141
10	1.277140	67.66212	3.139901	29.19798
Variance Decomposition of RCOD				
Period	S.E.	RCOBRET	RCOD	RCOWTI
1	1.266859	19.71484	80.28516	0.000000
2	1.463148	19.67026	80.32335	0.006391
3	1.502684	23.22261	76.47735	0.300037
4	1.546600	27.51847	72.19610	0.285434
5	1.561314	28.13069	71.51256	0.356750
6	1.574591	27.67603	71.96911	0.354863
7	1.584783	27.84271	71.80125	0.356031
8	1.592099	28.38649	71.25997	0.353535
9	1.596276	28.73156	70.88856	0.379876
10	1.598474	28.77177	70.77641	0.451818
Variance Decomposition of RCOWTI				
Period	S.E.	RCOBRET	RCOD	RCOWTI
1	0.813211	23.10687	74.16018	2.732949
2	0.954167	23.88091	71.40859	4.710498
3	0.988035	28.50231	66.78039	4.717296
4	1.029128	32.99765	61.58979	5.412567
5	1.053741	33.36717	59.61997	7.012857
6	1.071101	32.37289	59.46664	8.160460

7	1.083142	31.74102	59.01728	9.241706
8	1.091536	31.46313	58.31273	10.22414
9	1.096359	31.25923	57.81071	10.93007
10	1.099991	31.05744	57.44841	11.49416
Cholesky Ordering: RCOBRET RCOD RCOWTI.				

The variance decomposition results in Table 9 reveal how shocks to each benchmark crude oil price – Brent Blend (RCOBRET), Dubai/Oman (RCOD), and West Texas Intermediate (RCOWTI) – affect the forecast error variances of the others over a ten-period horizon. This allows us to understand the extent to which these benchmarks are influenced by their own innovations compared to innovations in other markets, based on the Cholesky order: RCOBRET → RCOD → RCOWTI. For RCOBRET (Brent Blend), the results show that it is initially 100% self-explanatory, meaning its forecast errors in period 1 are solely due to its own shocks. Over time, this self-dependence steadily decreases to around 67.66% in period 10, while the influence of RCOWTI increases to 29.20% and that of RCOD increases marginally to 3.14%. This means that WTI has a significant influence on Brent Blend prices over time and shows a strong interdependence, while Dubai/Oman has a smaller impact. For RCOD (Dubai/Oman), the variance is dominated by its own shocks across the 10 periods, ranging from 80.29% to 70.78%. The influence of RCOBRET increases from 19.71% to 28.77%, while RCOWTI remains negligible, never rising above 0.45%. This indicates that prices in Dubai/Oman are moderately affected by Brent Blend shocks but are largely isolated from WTI fluctuations.

For RCOWTI (West Texas Intermediate), the variance degradation shows the highest level of external influence. Initially, only 2.73% of the variance is self-driven, with Brent Blend contributing 23.11% and Dubai/Oman 74.16%. Over time, WTI's own contribution increases modestly to 11.49%, while Brent and Dubai/Oman continue to dominate at 31.06% and 57.45%, respectively. This means that the yield on West Texas Intermediate crude oil prices is highly sensitive to both Brent and Dubai/Oman shocks, especially the latter. The return on Brent Blend crude oil prices emerges as the most influential benchmark, significantly impacting the returns on Dubai/Oman and West Texas Intermediate over time. The return on West Texas Intermediate crude oil prices is mostly affected by external shocks, especially from Dubai/Oman. Dubai/Oman is the most independent, driven primarily by its own innovations, with moderate sensitivity to Brent. This dynamic reflects the interconnectedness and hierarchy of global oil benchmarks, with Brent Blend at the top of the influence structure of the Nigerian crude oil price framework.

4. Discussion of Results

The results in Table 6 present the Error Correction Model (ECM) estimates for Nigeria's crude oil stock market prices. Three ECM equations were derived to evaluate the adjustment dynamics and the short- and long-term interrelationships among the returns on Brent Blend, West Texas Intermediate, and Dubai/Oman. The error-correction term (ECT) reflects the speed at which deviations from long-term equilibrium are corrected. The ECT value for Brent Blend return (-0.507, $p = 0.03$) is statistically significant at the 5% level, indicating that approximately 50.7% of the imbalance will be corrected in the next period. This suggests a relatively rapid convergence of Brent prices back to equilibrium after a shock. In contrast, the ECT for West Texas Intermediate returns is positive (0.658) and marginally significant ($p = 0.060$), suggesting a slower, possibly divergent adjustment process. For Dubai/Oman, the ECT is -0.821, suggesting a strong alignment rate, although only slightly significant ($p = 0.072$), indicating moderate reliability. VEC residual diagnostic results indicate heteroscedasticity (F = 543,658), suggesting that the residual variance is non-constant and may affect the estimated effectiveness. The residues for the return on crude oil prices in Brent Blend and Dubai/Oman are not normally distributed ($p = 0.000$). In contrast, the return on West Texas Intermediate crude oil prices shows more normal behaviour ($p = 0.100$), suggesting that the model's assumptions are better met in this case.

These findings are consistent with previous studies that have documented asymmetric adjustment rates in the oil-price-stock market ratio, such as those by Sadorsky [10] and Kilian and Park [3], which emphasised regional and structural influences on oil market integration. The strong responsiveness of Brent and Dubai/Oman reversals to deviations from equilibrium supports previous literature suggesting that these markets exhibit robust co-movement and correction behaviours. CointEq1 captures a long-term cooperative relationship between Brent and West Texas Intermediate. The coefficient -2.026 means that a 1-unit increase in the return on West Texas Intermediate crude oil prices leads to a 2.026-unit increase in the return on Brent over the long term to maintain equilibrium. The positive constant (0.034) represents an interceptor or adjustment displacement. If the equilibrium is broken, Brent prices are sharply adjusted to restore balance. CointEq2 indicates a weaker long-term relationship between Dubai/Oman and West Texas Intermediate. The small positive coefficient (0.224) implies mild co-motion, and the constant (-0.049) implies a shift in equilibrium. Dubai/Oman appears to be less closely linked to West Texas Intermediate, which aligns with its regional price influence [1]. Short-term dynamics further reveal Brent's strong responsiveness to both CointEq1 and CointEq2, confirming its dominant role in restoring equilibrium. Previous values of Brent, and in particular the

return on West Texas Intermediate crude oil in delay 3 (0.533), significantly affect the Brent return, underscoring spillovers from West Texas Intermediate crude oil yields.

The returns on crude oil prices in Dubai/Oman have a mixed effect on those in Brent. This is synonymous with He and Wang [2], studies on the global economy and the world crude oil price: An analysis of cointegration with the Kilian economic index. Also, Dubai/Oman's adjustment to CointEq1 indicates weaker reactivity. Its own lagged values are generally negative, suggesting tendencies to return to the mean. Past values of West Texas Intermediate crude oil prices positively affect returns on crude oil prices in Dubai/Oman, especially amid delays, suggesting contagion from West Texas Intermediate returns. This is also in line with the study by Kilian and Park [3]. The returns on crude oil prices in Brent past values exert a negative influence, especially on lag 1. The returns on West Texas Intermediate crude oil prices also react positively to CointEq1, but less so than those on Brent. The equation suggests that the return on West Texas Intermediate crude oil prices follows rather than leads. It relies heavily on its own delays, especially delays 1 and 3, which indicate partial self-propulsion. Brent and Dubai/Oman delays are negatively impacting the return on West Texas Intermediate crude oil prices. The model's explanatory power is strong, with R-square values ranging from 61% to 66%, and the F-statistics confirm the model's sufficiency. All CointEq1 misexpressions are statistically significant, emphasising the existence of long-term equilibrium relationships. Figure 7 confirms the dynamic stability of VECM. All eigenvalues lie within the unit circle, confirming the system's stability and suggesting that shocks dissipate over time. This ensures reliable forecasts and meaningful policy analysis. The Granger causality results in Table 7 show bidirectional causality between Brent and Dubai/Oman (F = 4.607, p = 0.004; F = 8.485, p = 0.000), indicating mutual predictability.

There is unidirectional causality from Brent to West Texas Intermediate (F = 12.432, p = 0.000), but not the other way around. There is no causal link between West Texas Intermediate and Dubai/Oman in either direction. This confirms Brent's leading role in determining oil price dynamics. Similarly, Figure 8 and Table 8 show the results of the Impulse Response Function (IRF). Brent reacts strongly to his own shocks at first, but the effects diminish over time. Brent is also increasingly affected by West Texas Intermediate crude oil price shocks. The response of Dubai/Oman's crude oil prices to the Brent shock is significant and persistent, whereas its response to the return of West Texas Intermediate is small. West Texas Intermediate's returns are heavily influenced by those of Brent and Dubai/Oman crude oil prices, especially in the early periods, confirming its reactive nature. The variance decomposition results in Table 9 further reinforce these results. Brent's forecast error variance is initially self-driven (100%) but increasingly influenced by returns on West Texas Intermediate (29.20%) and Dubai/Oman (3.14%) crude oil prices. The return on crude oil prices in Dubai/Oman remains largely self-dependent (70.78%) but increasingly influenced by Brent. This aligns with Park and Ratti [9], who studied oil price shocks and stock markets in the U.S. and 13 European countries. Also, the return on West Texas Intermediate crude oil prices is heavily dependent on returns in Dubai/Oman and Brent, with its own limited influence (11.49%). These results underscore the hierarchical structure of global oil benchmarks. Brent is the most influential and has greatly shaped the dynamics of Dubai/Oman and West Texas Intermediate. Dubai/Oman is moderately linked, while returns on West Texas Intermediate crude oil prices are mostly reactive.

5. Conclusion

The study confirms the existence of strong short- and long-term links between Brent, West Texas Intermediate, and Dubai/Oman crude oil price benchmarks in the context of Nigeria's crude oil stock market. Brent serves as the leading benchmark and significantly influences both the returns on crude oil prices in Dubai/Oman and West Texas Intermediate. The return on crude oil prices in Dubai/Oman maintains some independence, while West Texas Intermediate plays a more reactive role. The dynamic stability and robust model fit reliably suggest forecasting potential.

5.1. Recommendation

- The Nigerian government should align its oil prices and export strategies more closely with Brent benchmark dynamics to improve forecast accuracy and revenue planning.
- Oil marketers and investors should monitor Brent price volatility as a leading indicator of regional and global price changes.
- Further studies should examine the impact of geopolitical and macroeconomic variables on the interaction among crude oil benchmarks to increase the model's robustness.

Data Availability Statement: Relevant data are available from the authors upon request for verification and replication purposes.

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