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DYNAMIC RELATIONSHIP BETWEEN OIL PRICE AND INFLATION IN OIL EXPORTING ECONOMY: EMPIRICAL EVIDENCE FROM WAVELET COHERENCE TECHNIQUE

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ABSTRACT

This paper examined the co-movement and causality between oil price and inflation using monthly data spanning between January 2007 and March 2020. The study employed the wavelet coherence techniques which are a new technique in economics and finance to verify the co-movement and causality simultaneously. Additionally, Granger and Toda Yamamoto's causality tests were deployed as a robustness check for the wavelet coherence techniques. Findings from the wavelet coherence technique reveal; (a) positive co-movement between the inflation and oil price between 2014M2 and 2017M1 at scale 4-8; (b) there is evidence of causality from oil price to inflation. Wavelet coherence technique revealed unidirectional causality running from oil price to inflation which is also confirmed by the Granger and Toda Yamamoto causality tests. To the author's understanding, no studies concerning oil price and inflation nexus in the case of Nigeria have deployed this technique. Based on these findings, recommendations were put forward.

Contribution/ Originality: The uniqueness of this study from past studies that examined this nexus stem from utilizing current methodology crafted from physics and engineering known as wavelet coherence technique. This approach has been utilized recently in econophysics to explore the co-movement and causality between economic and financial variables.

1. INTRODUCTION

The oil price-inflation connection has generated substantial discussion in academic, business, and policy circles. The strong interest in the nexus is explained by numerous reasons. Since 1970, after the United States and other European countries witnessed recession due to oil shock, caused by conflicts in the Middle East, significant attention has been given to the impact of oil price fluctuations on macroeconomic indicators including inflation. This caused several studies to verify the influence of oil prices on inflation. Some of these studies find oil prices to impact inflation positively whereas others detected negative and insignificant association respectively. One of the major deciders of the cost of production is crude oil. Thus, making it a major input in production processes. For instance, if the oil price increases, it will increase the transportation cost, thereby increasing the cost of goods and services. Hence, what is the level at which oil prices will influence changes in inflation? Based on this question, policymakers tend to investigate the oil price and inflation nexus. The vital function of the monetary authority of

any country is to guarantee price stability. With this role on them, they must ensure the stability of other macroeconomic variables that may affect their purpose. Therefore, knowing the impact of oil prices on inflation will assist the relevant authorities to formulate policies to absorb the shock of oil prices when it arises (Salisu, Isah, Oyewole, & Akanni, 2017). Furthermore, to ensure economic stability and lure foreign investors, inflation must be curbed. Hence the promotion of price stability must be ensured by both fiscal and monetary authorities. By analyzing the trend of crude oil since 1970, the world has experienced fluctuation in the price of crude oil which has impacted the global economy significantly. The aggregate output may be reduced temporarily due to volatility in the oil price which can lead to delay in business investment inducing sub-optimal sectoral reallocation of resources and raising uncertainty (Guo & Kliesen, 2005). The purpose of this paper is to investigate the co-movement and causality simultaneously between oil prices and inflation. Furthermore, to determine the causality direction between oil price and inflation. The remainder of the article is organized as follows. The theoretical framework is portrayed in the second section which is followed by the empirical studies in section three. The empirical methodology is discussed in the fourth section. The fifth section discusses the empirical findings. Section six ends the paper.

2. THEORETICAL REVIEW

In exploring oil price - inflation interaction we modify the modern Keynesian formulation of the short-run aggregate supply, that is, the short run Phillips curve equation. In order to establish the link between output gap and inflation, this model is selected. The short-run Phillip curve equation is specified by Romer (1996) as follows;

$$\pi_t = \pi_t + \lambda(INY - IN\bar{Y}) + \varepsilon_t^s; \ \lambda > 0 \qquad [1]$$

Where inflation is portrayed by $\pi_t \equiv InP_t - InP_{t-1}$, $(INY - IN\bar{Y})$ denotes a gap in output and the supply curve is illustrated by ε_t^s The (positive apriori slope) coefficient of Equation 1 implies that the output gap and inflation interconnection are positive. Therefore, in line with Equation 1, in the short run, inflation is expected to increase actual output more than the anticipated output. However, the Equation 1 will be modified to analyse the oil price and inflation interaction by introducing augmented lag values of the explanatory indicators. Deploying the framework of Catik and Önder (2011) the augmented backward-looking Phillip curve for the oil price is illustrated below:

$$\pi_t = \psi(L)\pi_t + \tau(L)y_t + \Phi(L)\Delta oil_t + \varepsilon_t^s \qquad [2]$$

Where the polynomial in the lag operator L of the inflation rate, gap of output and oil price are illustrated by Where $\psi(L), \tau(L) \text{ and } \Phi(L)$ respectively. The evaluated coefficients of all indicators; J, Y, and F are anticipated to be positive in Equation 2, whereas particularly, the coefficient magnitude of F relies on the economy's structure Catik and Önder (2011).

3. SYNOPSIS OF STUDIES

Before the oil price shock in the 1970s, attention was not given to the impact of oil price shock on inflation. However, over the years, many empirical studies have been conducted to investigate the influence of oil prices on inflation. The outcome obtained from those studies differs based on the time frame of the study, methodology deployed and the country of study. Therefore, leading to mixed findings from various investigators. In a study carried out in Taiwan by Lu, Liu, and Tseng (2010) on the nexus between volatility in oil price and inflation, using Bivariate GARCH model, the investigators deployed monthly data spanning between January 1986 and December 2008. Findings from this study revealed that the Oil price volatility Granger causes inflation. Also in the study

conducted by Gao, Kim, and Saba (2014) on the United States pertaining to the influence of oil price on inflation using monthly data stretching between 1974 and 2014.

Table-1. Studies summary.

Investigator(s)	Country	Study Period	Technique (s)	Result (s)
Atil, Lahiani, and Nguyen (2014)	Global	1997M1- 2012M9	NARDL	The price of gasoline, natural gas is impacted by the oil price.
Cartwright and Riabko (2015)	US & France	2006M1-2011M12	FGLS & GARCH	There is correlation between the price of wheat and spot oil prices
Gao et al. (2014)	US	1974M1-2014M7	Bivariate VAR	Inflation is majorly triggered by a significant increase in the prices of energy-related commodities
Catik and Önder (2011)	Turkey	1996M2 -2007M5	Markov Regime-switching framework	The asymmetric oil pass-through effect surfaced
Valcarcel and Wohar (2013)	US	1948Q1-2011Q2	Bayesian SVAR	There is shift in oil price-inflation pass-through from a supply-side to a demand-side.
Zhao et al. (2016)	China	2004Q1- 2012Q1	DSGE	Change in oil price affect real GDP and inflation
Lu et al. (2010)	Taiwan	1986M1-2008M12	Bivariate GARCH	Oil price cause inflation.
Wang, Wu, and Yang (2014)	Global	1980M1 2012M12	SVAR	Agricultural commodity is significantly impacted by oil price
Mukhtarov et al. (2020)	Azerbaijan	1995-2017	cointegration technique & VECM	The existence of long run cointegration was proven by the cointegration test.
Shaari et al. (2012)	Malaysia	2005-2012	Granger causality test	Oil price granger cause inflation
Zivkov, Đurašković, and Manić (2019)	Central & Eastern European nations	1996M1-2018M6	Wavelet-based Markov switching approach	Oil price does not significantly affect inflation
Al-Eitan and Al-Zeaud (2017)	Jordan	2000M1-2013M12	Variance Decomposition	Crude oil prices impact inflation in Jordan
Choi, Furceri, Loungani, Mishra, and Poplawski-Ribeiro (2018)	Developed & Emerging nations	1970-2015	Panel Regression	Oil price influence inflation positively
Asghar and Naveed (2015)	Pakistan	2000M1-2014M12	ARDL bounds & Granger causality.	Oil price and exchange rate influence inflation positively in the long-run
Adebayo. (2020)	Nigeria	2010M1-2020M3	Causality Tests & Wavelet Coherence Technique	Oil price cause exchange rate
Hammoudeh and Reboredo (2018)	US	2010-2017	linear ARDL model,	Changes in oil price cause changes in inflation
Nasir, Naidoo, Shahbaz, and Amoo (2018)	BRICS	1987QII – 2017QII.	TV-SVA	Each nation reacted in various ways in regards to the link between oil price and inflation prices
Bec and De Gaye (2016)	U.S, France & UK	2005Q1–2013Q12	Threshold nonlinear model	Oil price can significantly forecast inflation in each nation
Conflitti and Luciani (2019)	U.S & Euro Area	1984 - 2016	VAR model	Oil price passes through core inflation only via its impact on the economy.
Bala and Chin (2017)	Algeria, Angola, Libya & Nigeria	1995 -2014	ARDL dynamic panel	Oil price impact inflation positively
Ibrahim and Chancharoenchai (2014)	Thailand	1993Q1 - 2010Q2	Symmetric and Asymmetric Cointegration and ECM	Inflationary influences of oil price changes affect all sectors
Castro, Jiménez-Rodríguez, Poncela, and Senra (2017)	France, Germany, Italy and Spain	1996-2014.	Granger causality	The interaction between Inflation and oil price differs in different countries

The author utilized the Bivariate VAR to ascertain this influence. The result revealed that inflation is majorly triggered by a significant increase in the prices of energy-related commodities. To ascertain the correlation between future prices of wheat and spot oil prices, Cartwright and Riabko (2015) employed data covering the period between January 2006 and December 2011. The result from the FGLS and Diagonal GARCH illustrate the existence of a correlation between Wheat future prices and spot oil prices. In China, Zhao, Zhang, Wang, and Xu (2016) investigated the interconnection between oil price, inflation and real GDP employing quarterly data between 2004 and 2012. The investigators deployed DSGE to verify this connection. The study revealed that Oil price shock influence China's real GDP and inflation. In Malaysia, using monthly data stretching between 2005 and 2012, Shaari, Hussain, and Abdullah (2012) examined the impact oil price shock has on the inflation rate. The author used VECM to ascertain this interaction. Findings show cointegration between the variables in the long run while in the short run oil price influence inflation positively. Furthermore, the granger causality test provides a shred of supportive evidence for unidirectional causality running from oil price to inflation. Thus, making oil price a strong predictor of inflation in Malaysia. Mukhtarov, Aliyev, and Zeynalov (2020) examined the influence of oil price on macroeconomic indicators in Azerbaijan using the cointegration technique and VECM. To verify this link, time-series data stretching between 1995 and 2017 was deployed. The existence of long-run cointegration was proven by the cointegration test. The table below depicts a summary of literature on oil price and inflation. The summary of the studies is illustrated in Table 1.

The above summary of literature provides a sound overview of the information gained from ongoing discussion on how oil price is affecting inflation. Earlier researchers employed various modeling methods however the findings remain inconclusive. Additionally, research exploring the influence of oil price changes on inflation in Nigeria have used panel analysis, i.e., using annual data for Nigeria and other nations. This study thus, aims to fill the void in the literature by proposing and implementing a single nation and deploying monthly data.

4. EMPIRICAL METHODOLOGY

The investigator explored the time-frequency dependence between inflation and oil price by deploying the wavelet approach which was introduced by Goupillaud, Grossmann, and Morlet (1984). The main characteristic of most indicators used in economics or finance-based research is non-stationarity, so evaluating the causal effect of time-domain gives flawed and potentially unreasonable conclusions. Also, the "standalone frequency domain method main issue is commonly referred to the Fourier transformation, which emphasizes the frequency domain, that will result to the exclusion of data from the domain" (Pal & Mitra, 2017).

In our analysis this issue is avoided by using a wavelet-based Granger causality test. The volatility in Nigeria's oil price and crude oil is obtained by wavelet power spectrum.

Equation 1 represents the Morlet equation which is the technique first equation.

$$\varpi(t)\pi^{-\frac{1}{4}}e^{-i\varpi t}e^{-\frac{1}{2}t^2} \tag{3}$$

In Equation 3, where, w depicts frequency utilized on the time series restricted; p(t), n = 0, 1, 2, 3.......N-1; and $\sqrt{-1}$ is portrayed by i. ϖ is transformed, thus, transformed into $\varpi_{k,f}$. The transformation is explained by Equation 4:

$$\varpi_{k,f}(t) = \frac{1}{\sqrt{h}}\varpi\left(\frac{t-k}{f}\right), \ \ k,f \in \mathbb{R}, f \neq 0 \tag{4}$$

Where k represents the time and location while the frequency is illustrated by f. Kalmaz and Kirikkaleli (2019) recognise that the key elements when utilizing wavelet techniques are k and f respectively. Uncovering time-frequency linkage where continuous wavelet transformation is the key factor (CWT). Thus it is essential to connect these variables using the approach of CWT. Equation 5 depict the CWT.

$$\varpi_p(k,f) = \int_{-\infty}^{\infty} p(t) \frac{1}{\sqrt{f}} \varpi\left(\frac{t-k}{f}\right) dt, \tag{5}$$

The transition of the preceding time is portrayed as per Mutascu (2018) by p(t), and w illustrates the coefficient. This is represented below;

$$p(t) = \frac{1}{C_\varpi} \int_0^{\infty} \left[\int_{-\infty}^{\infty} |w_p(a,b)|^2 \, da\right] \frac{db}{b^2} \tag{6}$$

Equation 7 depict the variance of the wavelet power spectral of the time series;

$$WPS_p(k,f) |W_p(k,f)|^2 \qquad . \tag{7}$$

Kalmaz and Kirikkaleli (2019) and Adebayo (2020) Indicated that the Wavelet Coherence (WTC) calculates the cross-spectrum ratio to each time series spectral by combining their frequencies. The transition of the time-series is portrayed in Equation 8;

$$W_{pq}(k,f) = W_p(k,f)\overline{W_q(k,f)} \tag{8}$$

In Equation 8, the CWT of p(t) and q(t) is represented by $W_p(k,f)$ and squared value of WTC is depicted by $W_q(k,f)$. $R^2(k,f)$.

$$R^2(k,f) = \frac{\left|S\left(f^{-1}W_{pq}(k,f)\right)\right|^2}{S\left(f^{-1}|W_p(k,f)|^2\right) S\left(f^{-1}|W_q(k,f)|^2\right)} \tag{9}$$

In Equation 9, Zero (0) relationship will emerge between two time-series, if $R^2(k,f)$ Get closer to 0 whilst the relationship is shown if $R^2(k,f)$ is close to 1. Also, The $R^2(k,f)$ values did not specify the symbol of the correlation. Hence, Torrence and Compo (1998) "proposed a technique that can detect Wavelet coherence by utilizing variations in time-series wavering by deferral indicators" (Pal & Mitra, 2017). The wavelet coherence at the various level is shown in the Equation 10:

$$\phi_{pq}(k,f) = \tan^{-1}\left(\frac{L\{S(f^{-1}W_{pj}(k,f))\}}{O\{S(f^{-1}W_{pj}(k,f))\}}\right) \tag{10}$$

In Equation 10, the imaginary operator and a real part operator is illuststrated by L and O respectively.

In addition to the above approach, the study utilizes the time-domain causality techniques; (i) traditional Granger causality; and (ii) Toda Yamamoto causality to explore the causal interaction between inflation and crude oil price. Conventional Granger and Toda Yamamoto causality tests are generally known to explore; (i) whether

variable OP Causes Variable INF; (ii) whether variable INF cause variable OP; and (iii) whether both variables causes each other.

The general equation for the conventional Granger causality is represented by Equation 11 & 12.

$$OP_t = \alpha_1 + \sum_{i=1}^{v1} \alpha_i OP_{t-1} + \sum_{i=1}^{v2} \beta_1 INF_{t-1} + e_t$$

[11]

$$INF_t = \alpha_2 + \sum_{i=1}^{v3} \alpha_i INF_{t-1} + \sum_{i=1}^{v4} \beta_2 OP_{t-1} + \mu_t$$

[12]

The Toda Yamamoto causality general form is depicted by Equation 13 & 14

$$OP_t = \alpha_o + \sum_{i=1}^{m} \alpha_i OP_{t-1} + \sum_{i=m+1}^{m+dmax} \alpha_i OP_{t-1}$$
$$+ \sum_{i=1}^{m} \beta_1 INF_{t-1} + \sum_{i=m+1}^{m+dmax} \beta_1 INF_{t-1} + e_t$$

[13]

$$INF_t = \rho_o + \sum_{i=1}^{m} \alpha_2 INF_{t-1} + \sum_{i=m+1}^{m+dmax} \alpha_2 INF_{t-1}$$
$$+ \sum_{i=1}^{m} \beta_2 OP_{t-1} + \sum_{i=m+1}^{m+dmax} \beta_2 OP_{t-1} + \mu_t$$

[14]

The lag number that were used by the information criterion is indicated by m, the estimation parameters are denoted by α_o, α_i, and β_i respectively. μ, and e signifies the error term. To find a solution to the problems paramount to Granger causality test, Toda and Yamamoto (1995) modified the Wald test statistic was introduced, which overcome bias and spurious models based on an augmented VAR. Also, if the time series variables are integrated of the order 0, 1, or 2, Toda and Yamamoto causality test can be used.

5. EMPIRICAL RESULTS

The methodologies indicated above are applied to the set of data presented in this segment. The study utilized monthly data spanning between January 2007 and March 2020. The first analysis is a brief descriptive statistics of variables used which is followed by the unit root test. The wavelet coherence follows and the Granger and Toda and Yamamoto causality test which serves as a robustness test are presented in the last segment.

5.1. Descriptive Statistics

The Table 2 describes the descriptive statistics of the variables employed. All the variables utilized mirror a normal distribution as they are close to 0 as portrayed by the skewness. If the kurtosis is greater than 3, then the dataset has heavier tails than a normal distribution (more in the tails). Thus, all the variables portray normal distribution based on this yardstick. Figure 1 depicts the trend of the variables deployed.

Table-2. Descriptive statistics.

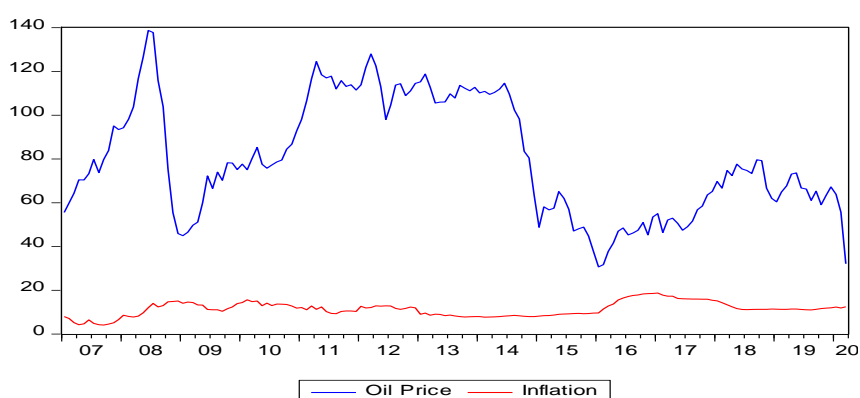| Variable	Inflation	Oil Price
Source	CBN	WTI
Timeframe	2007M1-2020M3	2007M1-2020M3
Symbol	INF	OP
Mean	11.37403	80.09126
Median	11.31000	75.11000
Maximum	18.72000	138.7400
Minimum	4.110000	30.66000
Std. Dev.	3.256627	26.56215
Skewness	0.092906	0.221843
Kurtosis	2.689055	1.865943
Jarque-Bera	0.869283	9.824502
Probability	0.647497	0.007356
Observations	159	159
Correlation Matrix		
INF	1	-0.356

Figure-1. Oil price and inflation trend.

5.2. Unit Root Test

The stationarity of each indicator was firstly tested utilizing the unit root test to verify the integration order of the variables before investigating the causal interaction between inflation and crude oil price. This study makes use of the two common traditional unit root tests; (ADF and PP) and DGLS. Furthermore, the effect of the structural break was put into consideration. Hence, Zivot & Andrew and Lee & Strazicich unit root test which are more recent unit root test that detect one and two structural break (s) respectively are deployed.

Table-3. Unit root test without structural break (s).

Tests	Included	INF	Decision	OP	Decision
ADF	K.	-8.51*	I(1)*	-7.58*	I(1)*
	K.&T	-8.54*	I(1)*	7.67*	I(1)*
PP	K.	-10.60*	I(1)*	-7.60*	I(1)*
	K.&T	-10.62*	I(1)*	-7.69*	I(1)*
DGLS	K.	-1.64***	I(1)***	-1.62***	I(1)***
	K.&T	-2.72***	I(1)***	-6.32*	I(1)*

Note: * depict the significance level of 1%.

Table-4. Unit root tests with structural break (s).

Tests	Included	INF	Decision	OP	Decision
ZA	K.	-6.58* [2016M6]	I(1)*	-8.05* [2016M2]	I(1)*
	K.&T	-6.80* [2016M3]	I(1)*	5.57* [2015M12]	I(1)*
LM	K.	-6.19 [2011M12]	I(1)*	-6.93* [2008M11]	I(1)*
	K.&T	{2016M1}		{2018M9}	

Note: * depict the significance level of 1%.

Tables 3 and 4 depict the unit root tests without structural break (s) and with structural break (s) respectively. Table 3 shows that all the variables are I(1) variables. Also Table 4 illustrates that all variables deployed are I(1) variables.

5.3. Wavelet Coherence Result

When interpreting wavelet coherence (WTC), the grey cone signifies the cone of influence which will be utilized for interpretation whereas the significance level which is depicted by the thick black line is calculated based on the Monte Carlo simulations. Additionally, when the correlation is weak between two indicators, it is depicted by colder colors (blue) while warmer color (red) illustrates a strong correlation between the two variables. Rightward arrows illustrate positive interaction between the two indicators while negative interaction in denoted by leftward arrows. Additionally, when the arrows point rightward and up, or leftward and down, it show that second variables cause the first variable. Thus, the second variable causes the first variable. Also, if the arrows point leftward and up or rightward and down, it show that the first variable causes the second variable.
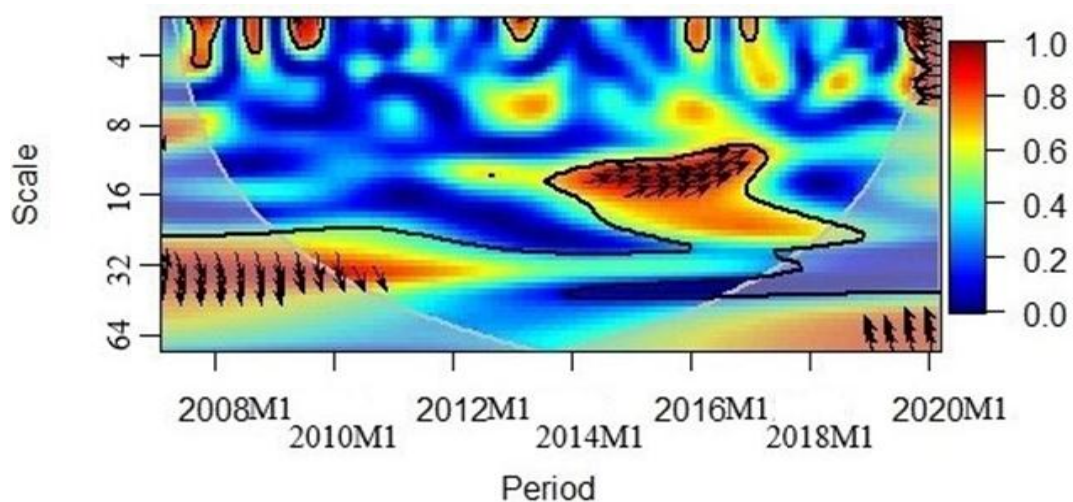

Figure-2. WTC between inflation and oil price.

Figure 2 portrays the wavelet coherence between inflation and crude oil between 2007M1 and 2020M3 in Nigeria. At scale 16-32, the correlation between inflation and oil price is positive. Though between 2011M1, and 2014M1 the variables are out of phase illustrating zero correlation between oil price and inflation. Furthermore, between 2014M2, and 2017M1, at scale 4-8, there is evidence of a positive relationship between inflation and oil price. This revealed that when the price of oil increases, the inflation rate increases (Asghar & Naveed, 2015; Gao et al., 2014; Zhao et al., 2016). Furthermore, the rightward and up arrow shows that oil price cause inflation. However, between 2019M12, and 2020M3, at scale 2-4, there is evidence of a negative relationship between inflation and oil price. The rightward and up arrows provide supportive evidence for causality running from oil price to inflation. This shows that oil price is a good predictor of inflation (Lu et al., 2010; Mukhtarov et al., 2020)

5.4. Time-Domain Causality

Findings from the Table 5 illustrate the result of the Granger and Toda Yamamoto causality tests. There is evidence of a one-way causality from oil price to inflation i.e. increase in inflation is a result of oil price. This finding complies with several studies (Lu et al., 2010; Valcarcel & Wohar, 2013). These findings provide supportive evidence for the wavelet coherence result. Hence, oil prices can significantly predict inflation in Nigeria.

Table-5. Causality Tests.

Tests	Causality Direction	Lag (s)	X^2/MWALT[b]	P-Value	Decision
Granger Causality	OP→ INF	6	2.187	0.032**	Reject H$_0$
	INF→ OP	6	0.522	0.837	Do not Reject H$_0$
Toda Yamamoto Causality	OP→ INF	8	17.497	0.025**	Reject H$_0$
	INF→ OP	8	4.1837	0.840	Do not Reject H$_0$

Note: → portrayed the direction of causality, * denotes 1% statistical significance, ** stand for 5% statistical significance, & *** signifies 10% statistical significance correspondingly. Optimal lag based on AIC. MWALT[b] mirrors Modified Wald.

6. CONCLUSION

Using monthly data spanning between January 2007 and March 2020, this study investigates the co-movement and causality between oil price and inflation interaction in the case of Nigeria by employing a new econometric technique in economics and finance used to examine co-movement and causality simultaneously. Additionally, Granger and Toda Yamamoto's causality tests were deployed as a robustness check for the wavelet coherence techniques. Findings from the wavelet coherence technique reveal; (a) positive co-movement between the inflation and oil price between 2014M2 and 2017M1 at scale 4-8; (b) there is evidence of causality from oil price to inflation. Both Granger and Toda Yamamoto causality test revealed unidirectional causality running from oil price to inflation. This finding complies with the outcome of the wavelet coherence, thus providing a supportive evidence for the wavelet coherence technique. Based on these findings, the paper suggests the need to diversify Nigeria's revenue streams. Furthermore, an established agricultural sector will help to provide additional sources of revenue to handle the fluctuations resulting from shifts in crude oil prices on which the nation has become so heavily dependent.

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