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# Intervention Modelling of Crude Oil Prices Using Pre- and Post-Transfer Function Models

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**Abstract**
In order to model Nigerian crude oil prices, the study used Autoregressive Integrated Moving Average Intervention models. The rapid decline in the series was manifest in the time plot, necessitating an intervention process. The data were separated into pre-intervention and post-intervention series. At order one, the series was examined for stationarity. Four models were estimated based on AIC. There were pre- and post-intervention sections. To reduce the erroneous correlation effect between the pre- and post-intervention data, they were pre-whitened. The pre-whitened input series (pre-intervention series) and output series (post-intervention series) were both pre-whitened, and the cross-correlation between the two was investigated. The cross-correlation behaviors were used to generate a rational polynomial representation for the dynamic transfer function models. It was revealed that the calculated noise was autocorrelated. This filled up the gaps in the transfer function model, which was then used to fit the entire model. The resulting model was subjected to a diagnostic test and determined to be suitable.

**Keywords:** Intervention, Pre-Post Intervention, Transfer Function Model, Crude Oil Prices, Pre-Whitened.

## Introduction

The Nigerian government primarily receives its revenue from the production and sale of crude oil. The Nigerian National Petroleum Corporation reports that oil was discovered in 1956 at Oloibiri, Bayelsa State. Shell D'Arcy, now Shell Petroleum, was discovered after conducting extensive exploratory activities that began in 1938. When Nigeria's first oil field went online in 1958, it became one of the world's largest oil producers, producing 5,100 barrels of oil per day and gaining international recognition for its oil production. Nigeria is now OPEC's fifth-biggest exporter and Africa's largest oil producer, accounting for 33-35% of the continent's oil and gas output. Intervention models are required since commodity production and sales have been falling for some time. The most widely used method for modelling time-series data is the Jenkins' Autoregressive Integrated Moving Average (ARIMA) model. However, when an external event, such as growth, reduction, or regular movement, affects the patterns of the series under study, the ARIMA model may be impacted. Wiri and Tuaneh (2019). They can accomplish this effectively if they use the appropriate tools, such as the ARIMA-Intervention model. There are three types of interventions: ramps, pulse points, and stairs. Step Intervention begins at a given time and continues. The effect of step intervention may increase, decrease, or remain constant over time.. This type of domestic market intrusion is the result of new economic policies. Box et al. (1994). The intervention model is used to explore how the interest rate rises and falls. When using the autoregressive integrated moving average (ARIMA) intervention model on any series, the purpose is to assess the dynamic influence on both the variable's mean level and other events influencing the series. The Box-Tiao technique of the ARIMA intervention model will be used in the study to examine crude oil prices in Nigeria between January 1986 and June 2017.

Etuk (2012) examined monthly Nigerian Treasury bill rates from January 2006 to December 2014 using the Box-Jenkins approach. The temporal plot of the data showed a pattern of decline from 2006 to 2009 and an increase through 2013. The seasonal changes over 12 months show a horizontal tendency, and the seasonality is not evident. The stability of the monthly Treasury bill rate was demonstrated when it passed the stationary test. The ACF figure, which displays a negative point at lag 12, is revealing of seasonality. A reliable model for rates on Treasury notes is seasonal ARIMA (011)(011).

Etuk (2013) looked at Nigeria's daily Naira-Euro exchange rates from December 8, 2012, to March 30, 2013. In his investigation, the exchange rate time plot indicates an upward and downward pattern from December 2012 to early February 2013, followed by a decreasing trend from then until late March. The exchange rate between the naira and the euro does not appear to be seasonal; nonetheless, both seasonal and non-seasonal discrepancies are reducing. The ACF plot demonstrated seasonality at period 7, as seen by a negative spike at lag 7. He concludes that the Naira-Euro exchange rates adhere to the SARIMA (011)*(011) models.

Victor-Edema and Essi (2020). Model current account and exchange rate using the transfer function; the series was found to be non-stationary, with stationarity detected at lag 1. To validate the two-stationarity series, the Dickey-Fuller test was applied. The cross-correlation function and the Box-Jenkins autoregressive approach were used to identify the input series as part of the transfer function procedure. In both series, pre-whitening was used. A noise model was utilized to run diagnostic tests on the projected function.

Iwok (2016) used the transfer function technique to simulate Naira exchange rates in US dollars and Swiss francs. The two series were checked for stationarity using the appropriate transformation after the input and output series had been pre-whitened to reduce the influence of spurious correlations. The input series was fitted using the autoregressive integrated moving average (ARIMA(1,1,0)) model. The cross-correlation of pre-whitened input and output was examined. The cross-correlation demonstrated that a rational polynomial might perhaps represent the dynamic transfer function.

In order to model crude oil prices in Nigeria, Wiri and Essi (2018) looked at the use of ARIMA Intervention. The study's data set covered the years January 1986 through June 2017. The goal is to determine the dynamic effect on the variable's mean levels and other events that have an impact on the series. They looked at the series' time plot to reach the study's goal; this revealed an abrupt spike in the series, which necessitated the use of intervention modelling. The actual series, pre-intervention series, and post-intervention series were the three sets of data that were used in the study. The series were all found to be non-stationary at levels after the data were differenced using the Augmented Dickey-Fuller (ADF); however, the real, pre-, and post-intervention series were not stationary at first difference. The best model was the pre-interference model with the lowest (AIC) (ARIMA-(111)), with an AIC of 4.5. The residual correlogram graphic showed the model's appropriateness. The residual histogram was normally distributed with probability values, and no spike cut the level of the correlogram, showing that the model was correct (0.0000).

## Methodology

### Arima Model

The series' limited means and error parameters are simulated using an autoregressive integrated moving average technique. The AR model includes lagged terms for the series, while the MA model includes lagged terms for the error. The ARMA model is formed by combining both lagged terms. As a result, ARMA (P.Q), where p is the order of the autoregressive parameter and q is the order of the moving-average coefficient, can frequently be represented as [9]

$$Y_t = \sum_{i=o}^{p} \alpha_i Y_{t-i} + \varepsilon_t - \sum_{t=1}^{q} \theta_i \varepsilon_{t-i} \quad (1)$$

The data $\{Y_{t-i}\}$ follows an autoregressive moving average model of orders p and q, known as ARMA (p, q). Constants $\alpha_i$ and $\theta_i$ ensure the model is stationary and invertible, and $\varepsilon_t$ is a white noise process. Let model one be rewritten as:

$$A(B) y_t = B(L)\varepsilon_t \quad (2)$$

Where $A(B) = 1 - \beta_1 B_1 - \beta_2 B_2 - \dots - \beta_p B_p$ (3)

$$B(L) = 1 + \theta_1 B_1 + \theta_2 B_2 + \dots + \theta_q B_q \quad (4)$$

B is the backshift operator defined by


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$B_t^k y_t = y_{t-k}$

**Intervention**

External events such as holidays, strikes, sales campaigns, and legislation changes can all have an impact on time series. We refer to this as the external event intervention time. The two basic forms of intervention variables are pulse function and step function.

**Pulse Function**

A pulse function indicates that intervention occurs at a particular time index. $(t_1)$. The pulse function is mathematically expressed as [8]

$$P_t = \begin{cases} 0 & if \;\; T \neq t_1 \\ 1 & if \;\; T = t_1 \end{cases} \quad (5)$$

**Step Function**

A step function describes the intervention process as a continuous stage, beginning with the time index $(t_1)$. In mathematics, the step function is

$$S_t = \begin{cases} 0 & if \;\; t < t_1 \\ 1 & if \;\; t \geq t_1 \end{cases} \quad (6)$$

The pulse function can be obtained by differentiating the step function.

$$P_t \; (1 - B)S_t \quad (7)$$

An intervention model can also be represented using the pulse or step function. The selection of specific forms is usually based on the ease of interpretation. Wiri & Tuaneh (2019)

**Estimation Of Impulse Response Weights**

The intervention model takes the form

$$Y_t = \text{V(B)} I_t + K_t \quad (8)$$

Where $Y_t$ and $I_t$ are indicator variables,

$I_t$=$P_t$=$S_t$

V(B)= $\frac{\omega(B)}{\delta(B)}$B$^{b,}$

$$V(B)= (v_0+v_1B+v_2B^2+v_3B^3+v_4B^4+\ldots\ldots\ldots\ldots) \quad (9)$$

$$\delta(B)= (1 +\delta_1B+B^2\text{-}\delta_3B^3\text{-}\delta_4B^4\text{-}\ldots\ldots\ldots\ldots\text{-}\delta_rB^r.) \quad (10)$$

$$\omega(B)= (1 +\omega_1B+B^2\text{-}\omega_3B^3\text{-}\omega_4B^4\text{-}\ldots\ldots\ldots\ldots\text{-}\omega_rB^r.) \quad (11)$$

$$(1+\delta_1B+B^2\text{-}\delta_3B^3\text{-}\delta_4B^4\text{-}\ldots\ldots\ldots\ldots\text{-}\delta_rB^r.)(v_0+v_1B+v_2B^2+v_3B^3+v_4B^4+\ldots\ldots\ldots\ldots)= (1 +\omega_1B+B^2\text{-}\omega_3B^3\text{-}\omega_4B^4\text{-}\ldots\ldots\ldots\ldots\text{-}\omega_rB^r.)B^b \quad (12)$$

The transfer function model can be expressed by the ratio of two characteristic polynomials in $B$, b The weights and time delay for the intervention effect $w_j$, polynomial $\omega(B)$, frequently represent the anticipated first impacts of the action.

. The polynomial $\delta(B)$. On the other hand, it assesses the behavior of the persistent influence on intervention.. Ntebogagng (2015)

Equating the parameter of the model and applying the principle of mathematical induction.

$$V_j=0 \qquad j < b \quad (13)$$

$$V_j=\delta_1V_{j-1}+\delta_2V_{j-2}+\ldots\ldots\ldots\ldots\delta_rV_{j-r}+\omega_0 \qquad j = b \quad (14)$$

$$V_j=\delta_1V_{j-1}+\delta_2V_{j-2}+\ldots\ldots\ldots\ldots\delta_rV_{j-r}+\omega_0$$

$$V_j=\delta_1V_{j-1}+\delta_2V_{j-2}+\ldots\ldots\ldots\ldots\delta_rV_{j-r}\text{-}\omega_{j-b} \qquad J=b+1, b+2, \ldots\ldots\ldots\ldots.b+s \quad (15)$$

$$V_j=\delta_1V_{j-1}+\delta_2V_{j-2}+\ldots\ldots\ldots\ldots\delta_rV_{j-r} \qquad j > b+s \quad (16)$$

**Identification of the Arima Process**

The identification applies to the series or data that is well characterised by an autoregressive integrated moving average of order (p.d.q) (ARIMA-(p.d.q)). In a practical system, the process will be infected by a disturbance term (Noise), which has the net consequence of reducing the system's output.. The error term is expressed as Pong-Wai (1979)

$K_t = \frac{\theta(B)}{\varphi(B)}\varepsilon_t$, (17)

$\theta(B)$ *is* MA parameter

$\theta(B)\varepsilon_t = 1+\theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q$ (18)

$\varphi(B)$ *is* AR parameter

$\varphi(B)z_t = 1+\varphi_1 B + \varphi_2 B^2 + \cdots + \varphi_p B^p$ (19)

The combined transfer function Noise models are designated as:

$(1-\delta_1 B - \cdots \ldots \ldots \ldots . . + \delta_r B^r)Y_t = (\omega_0 - \varphi_1 B - \cdots \ldots \ldots \ldots . . - \varphi_S B^S)X_{t-b}$

ARumilgag & Anilhakumar (2013).

$Y_t = \frac{(\omega_0 - \varphi_1 B - \cdots \ldots \ldots - \varphi_S B^S)X_{t-b}}{(1-\delta_1 B - \cdots \ldots \ldots - \delta_r B^r)} + \frac{1+\theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q}{1+\varphi_1 B + \varphi_2 B^2 + \cdots + \varphi_p B^p}\varepsilon_t$ (20)

**Identification of Transfer Function Models**

**The cross-correlation function method**

The cross-correlation function identifies stochastic processes. Cross-correlation of the input and output series is one method for determining transfer functions. The cross correlation for lag k can be expressed as follows: Wiri & Rechard (2022)

$\rho(XY) = \frac{C_{XY}}{S_X S_Y}$ (21)

$C_{XY} = \frac{1}{n}\sum_{t=1}^{n-1}(X_t - \bar{X})(Y_t - \bar{Y}) \quad K = 0,1,2 \ldots \ldots \ldots \ldots \ldots \ldots$

**Pre-Whitening**

Assume the process is stationary and follows an autoregressive integrated moving average model, which is expressed as

$X_t = \theta X_{t-1} + \ldots\ldots\ldots + \theta_p X_{t-p} + \alpha_t$ (22)

The models are transformed to the correlated input $X_t$ and output $Y_t$

$\alpha_t = X_t - (\theta X_{t-1} + \ldots\ldots\ldots + \theta_p X_{t-p})$ (23)

In terms of the input and rewriting the equation in terms of the output

$\beta_t = Y_t - (\varphi Y_{t-1} + \ldots\ldots\ldots + \varphi_p Y_{t-p})$ (24)

$\alpha_t$ and $\beta_t$ represent the input and output series of the post-intervention and pre-intervention process. Chung & Chan (2009)

**Results**

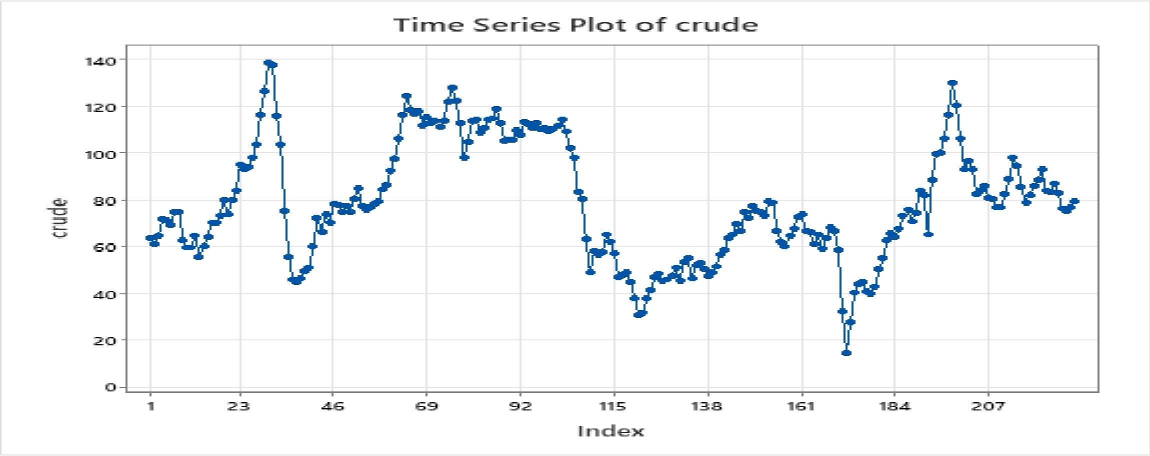
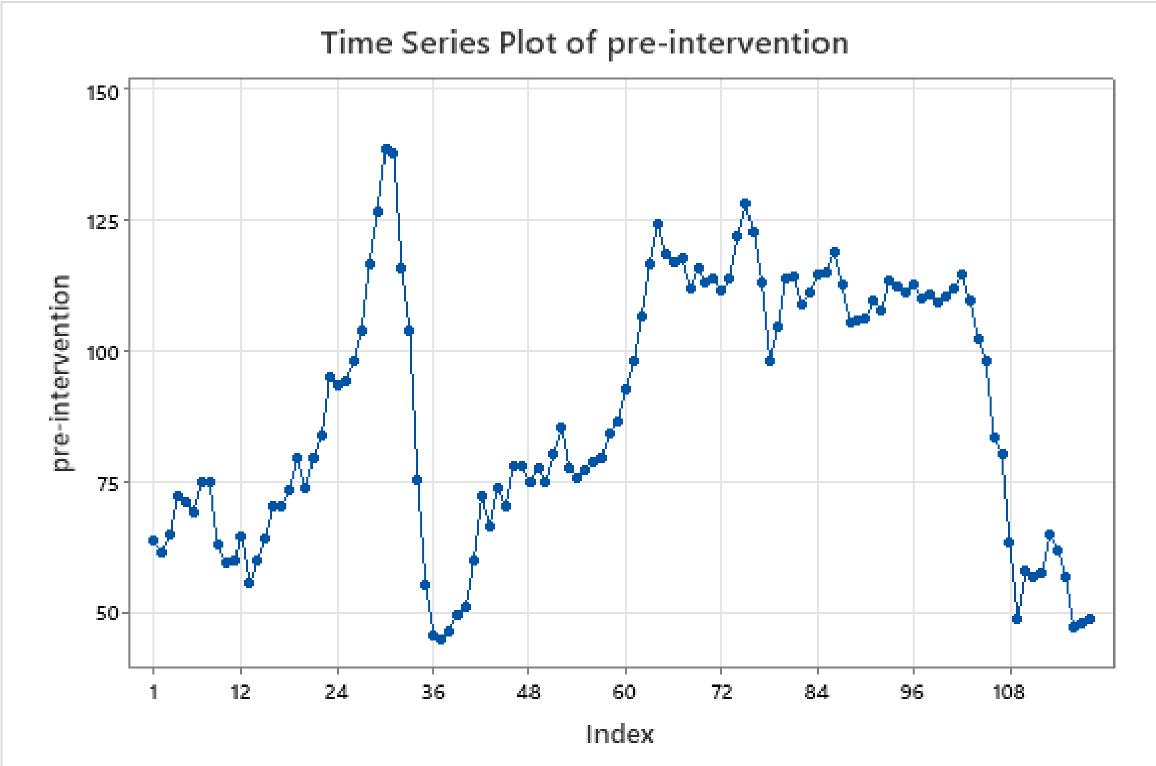



**Figure 1.1:** **Time Plot of Crude Oil Prices**



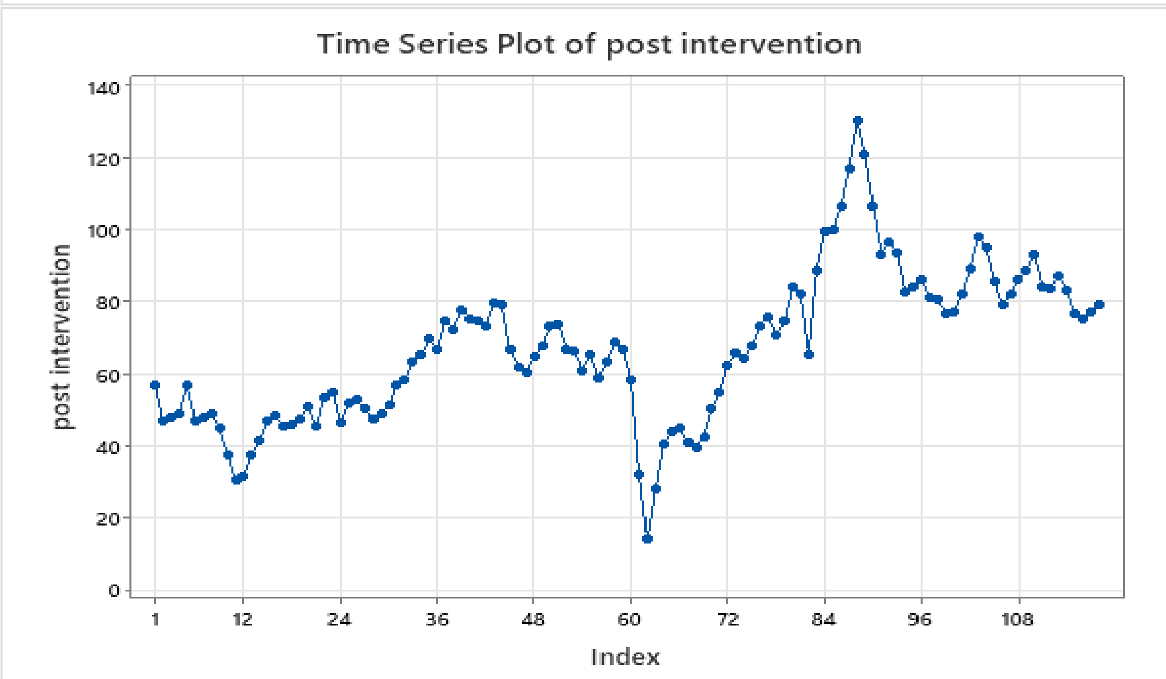




**Figure 1.2 Empirical  Plot Of Pre And Post-Intervention Series**.


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**Table 1.1: Stationarity Test**

| parameter | Lev | 1st diff | T -C -V | |
|---|---|---|---|---|
| Crude oil price | -2.740865(0.069) | -11.41614(0.000) | 1% | -3.493747 |
| Preintervention | -2.79905(0.0618) | -6.281786 (0.00) | 5% | 2.889200 |
| Post intervention | -1.5604(0.498) | -8.01032(0.00) | 10% | -2.581596 |

**Table 4.2: Estimation of Arima and ARIMA-Intervention Models With Aic and Sic Values**

| REPRESENT | CO-EFFICIENT | | | | AIC | SIC |
|---|---|---|---|---|---|---|
| | AR(1) | AR(2) | MA(1) | MA(2) | | |
| ARIMA-(1.1.1) | 0.938(0.00) | | 0.267(0.00) | | 6.809 | 6.884 |
| ARIMA(211) | 1.312(0.00) | -0364(0.02) | -0.673(0.68) | | 6.805 | 6.886 |
| ARIMA(212) | 0.648(0.036) | 2.533(0.384) | 0.6(0.063) | 0.25(0.009) | 6.806 | 6.904 |
| **ARIMA(112)** | **0.918(0.00)** | | **0.333(0.00)** | **0.15(0.003)** | **6.7997** | **6.881** |

$$(1-0.9189B)(1-B)X_t - 0.333\varepsilon_{t-1} - 0.153\varepsilon_{t-2} = \alpha_t \quad (25)$$
$$X_t - 1.9189X_{t-1} + 0.91893X_{t-2} - 0.333\varepsilon_{t-1} - 0.153\varepsilon_{t-2} = \alpha_t \quad (26)$$

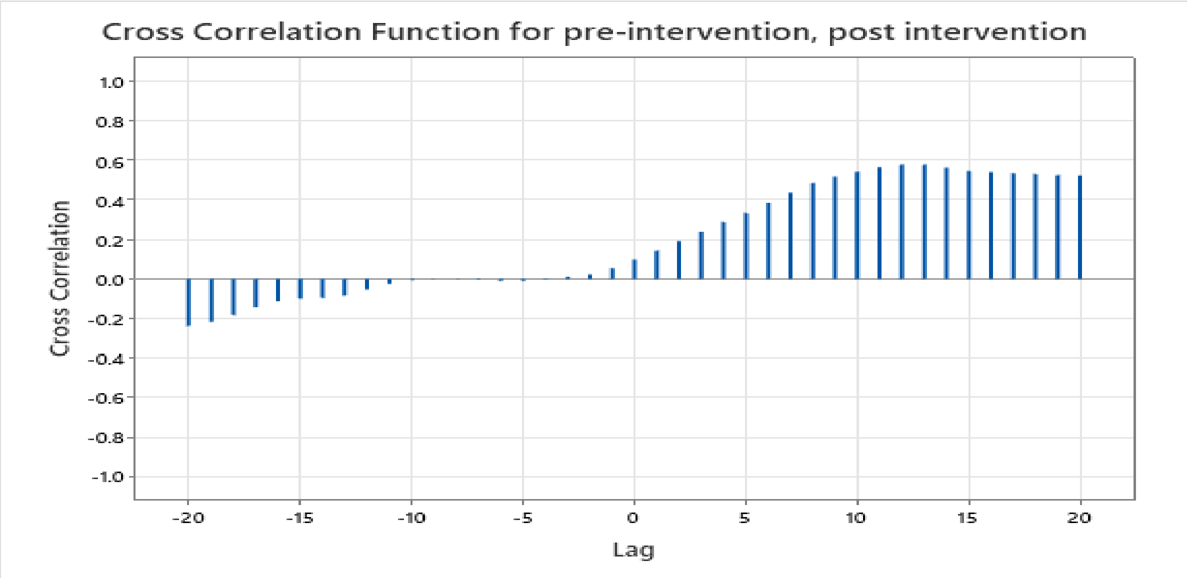
**Pre-whitening of $X_t$ and $Y_t$**

input series models

$$\widehat{\alpha_t} = X_t - 1.9189X_{t-1} + 0.91893X_{t-2} - 0.333\varepsilon_{t-1} - 0.153\varepsilon_{t-2} \quad (27)$$

output series models

$$\widehat{\beta_t} = Y_t - 1.9189Y_{t-1} + 0.91893Y_{t-2} - 0.333\varepsilon_{t-1} - 0.153\varepsilon_{t-2} \quad (28)$$




.

**Figure 4.2: Cross-correlation between the pre- and post-intervention series**

**Estimation of impulse response function $V_j$ The Order Of (R, B, S)=(2,2,2)**

$(1+\delta_1 B+\delta_2 B^2)(v_0+v_1 B+v_2 B^2+v_3 B^3+v_4 B^4+\ldots\ldots\ldots\ldots) = (\omega_0-\omega_1 B-\omega_2 B^2.)B^2$

$V_j=0$ if $J < 9$ (29)

$V_0=.V_1 \ldots\ldots\ldots\ldots\ldots..V_8 = 0$

$V_9= w_0$ =0.52 , $V_{10}$=0.545 $V_{11} = 0.57, V_{12} = 0.58, V_{13} = 0.5804$

$V_{10}= w_0$ $J = B = 9$ (30)

$w_0$=0.52

$\boldsymbol{V_{10}}= \delta_1 V_9-W_1$ $j = b + 1$ (31)

$\mathbf{0.545} = 0.52\delta_1-W_1$

$\boldsymbol{V_{11}}= \delta_1 \boldsymbol{V_{10}}+ \delta_2 V_9- W_{2,}$ $j = b + 2$ (32)

$\mathbf{0.57} = \mathbf{0.545}\boldsymbol{\delta_1}+\mathbf{0.52}\boldsymbol{\delta_2} - W_2$ (33)

$j > b + s$

$\boldsymbol{V_{12}}= \delta_1 \boldsymbol{V_{11}}+ \delta_2 V_{11}$ (34)

$0.58 = 0.57\delta_1+0.545\delta_2$ (35)

$\boldsymbol{V_{13}}= \delta_1 \boldsymbol{V_{12}}+ \delta_2 V_{11}$ (36)

$0.5804 = 0.58\delta_1+0.57\delta_2$ (37)

From the above equation, we can solve for $(\delta_1, \delta_2, w_1\ and\ w_2)$

$\delta_1$=0.99, $\delta_2$= 0.4654, $w_1 = -0.298, w_2$=-0.22 (38)

Thus, the preliminary identification suggests a tentative transfer function model.

$(1 - 3.58B + 2.54B^2)X_t= (0.824 - 2.58B + 0.068B^2)Y_{t-2}$ (39)

Or

When $V(B)= \frac{(0.52+0.298B+0.2244B^2)B^2}{(1+0.99B+0.654B^2)}$ (40)

$X_t= V(B)Y_t+ N_t$ (41)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**Identification of Noise Model**

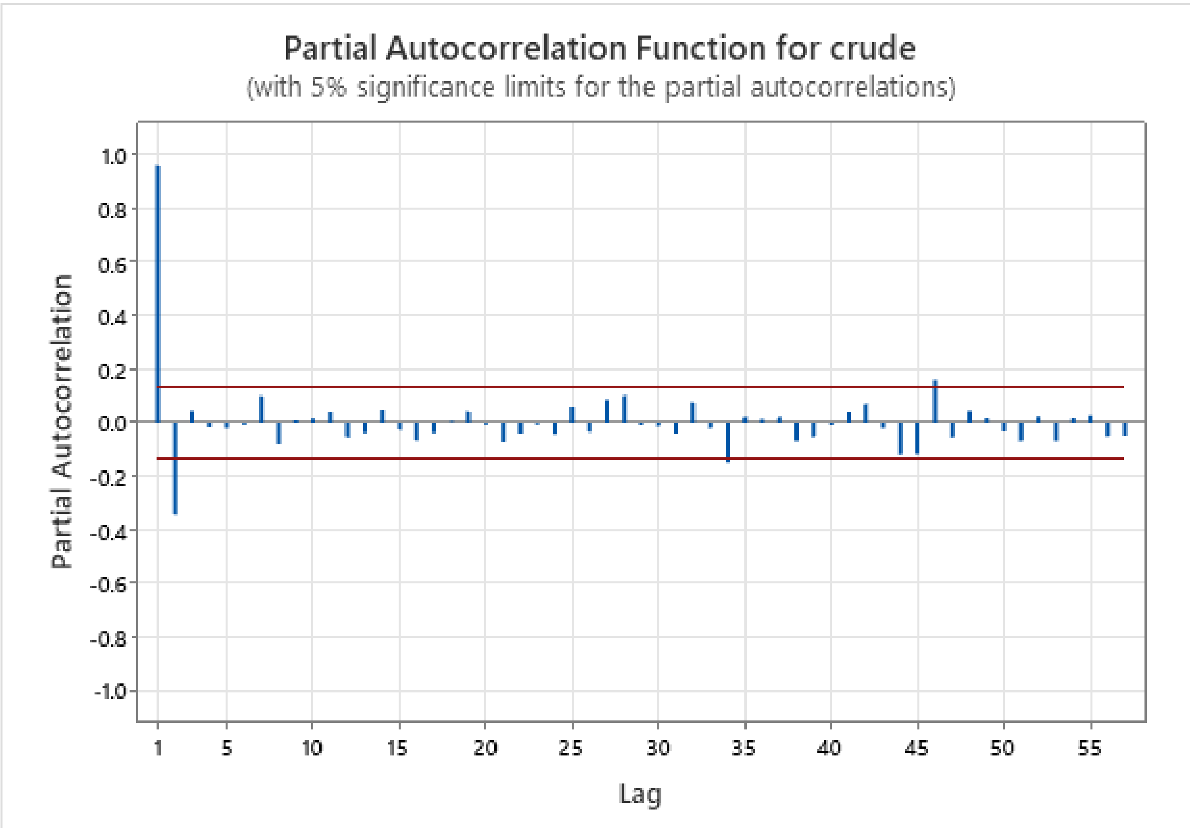


**Figure 4.3: Partial Autocorrelation Function**

$(1-\emptyset_1 B)\varepsilon_t=\alpha_t$ (42)
$(1-1.9B+0.92B^2-0.33B+0.15B^2)N_t=\varepsilon_t$ (43)
$(1-0.95B)\,(1-1.9B+0.92B^2)N_t=\alpha_t$ (44)
$N$ T may be represented as a second-order autoregressive model.

$(1-2.853B+2.72B^2-0.97B^3)N_t=\alpha_t$ (45)

$N_t=\left(\frac{1}{1-2.853B+2.72B^2-0.97B^3}\right)\alpha_t$ (46)

.

$Y_t=\frac{(\omega_0-\varphi_1\mathrm{B}-\cdots\ldots\ldots-\varphi_S\mathrm{B}^S)X_{t-b}}{(1-\delta_1\mathrm{B}-\cdots\ldots\ldots-\delta_r\mathrm{B}^r)}+N_t$ (47)
$Y_t=\frac{(0.52+0.298B+0.2244B^2)X_{t-2}}{(1+0.99B+0.654B^2)}+\left(\frac{1}{1-2.853B+2.72B^2-0.97B^3}\right)$ (48)

**Discussion**

The time plot of monthly crude oil prices from Jan 2006 to December 2024 was obtained from www.cenbank.org. The Central Bank of Nigeria's website provides monthly data on Nigerian crude oil prices in US dollars per barrel. In Figure 1.1, the time plot of the series showed an erratic movement, with a rapid downward movement in 2015. The effect began at time $t_1$ = 116. Suggesting further government intervention in crude oil production and sales. As a result, there is only one intervention point, indicating that crude oil production and sales are dropping. Mishra et al (2018). Thus, we identify the intervention point; it can be characterized as follows: pre-intervention period (2006–2015) and post-intervention period (2016–2024). The data was divided into two portions, as shown in Figure 1.1. The plot of the pre- and post-intervention process is shown in Figure 1.2. The series is showing an irregular movement. The data for pre- and post-intervention were tested for stationarity using the Dickey-Fuller (ADF) test. The result in Table 1.1 shows this information. At the level, beginning difference, and probability values in brackets, reflect the (ADF) test result. At a given level, the probability values, or p-values. The findings revealed that the unit root was present at the level. Initially, the crude oil price, pre-intervention series, and post-intervention series all remained stationary. Table 1.2 displays the four ARIMA models computed with the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC). The best model for Nigerian crude oil prices is ARIMA (1,1,2) with the minimum information criterion. AIC (6.7997) and SIC (6.881), resulting in the model (Gujarati,2013). However, the association between the pre-whitening series presented above is statistically significant at delays 1-6. In order to identify the error in the model, the partial autocorrelation was used. A spike in lag 1 of the partial autocorrelation function indicates the presence of an autoregressive model of order one, AR(1). The Transfer Function -white Noise Model of crude oil prices uses pre- and post-intervention series as input, and the output is in Eq. 48

**Conclusion**

The study used an autoregressive integrated moving average approach to forecast crude oil prices before and after the intervention in a set of transfer function models. The input and output series experienced pre-whitening, and the resulting equation was used to describe the variable's dynamic transfer function. Four models were estimated for the series, with ARIMA (1,1,2) providing the best fit according to information criteria.

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