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Cointegration Analysis of the Relationship between the Prices of Crude Oil and Its Petroleum Products in Ghana

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Abstract

This paper investigates the relationship between prices of crude oil and its petroleum products such as Gasoline, Gas oil, Residual fuel oil (RFO) and premix fuel in Ghana. The monthly data of Brent crude oil and the prices of petroleum products for the period from January 2009 to June 2019 were used. The Autoregressive Distributed Lag (ARDL) Bounds cointegration test was employed to show the existence of a long run relationship between crude oil prices and the prices of petroleum products. An ARDL-based error correction model (ECM) was used to estimate the short and long run effect between the variables. Results from the cointegration test revealed the inexistence of a long run relationship between the prices of crude oil and premix fuel prices. It was established that while crude oil prices have both short and the long run effects on the prices of Gasoline, Gas oil and Residual fuel oil, inflation had significant positive effect on only the prices of residual fuel. Exchange rate had significant negative effects on the prices of Gasoline, Gasoil and Residual fuel oil in both the short and long run. Results from the Wald's Granger Causality test indicated a uni-causal relationship running from Crude oil to Gasoline, Gas oil and RFO. There is no causal relationship between Inflation rate and Gasoline, Gas oil.

Keywords

Crude Oil, Petroleum Products, Bounds Cointegration Test, ARDL-ECM

1. Introduction

Crude oil is presently one of the most important sources of energy and commodity in the global economy [1]. The energy, industrial, domestic, transportation and economic sectors heavily depend on crude oil. According to [2] Crude oil is a mixture of hydrocarbons (compounds composed mainly of hydrogen and carbon), though it also contains some nitrogen, sulfur, and oxygen. Crude oil is extracted with giant drilling machines. After crude oil is removed from the ground, it is sent by pipeline, ship or barge to a refinery, where different parts of the crude oil are separated into useable petroleum products [3]. Petroleum products include light distillates (LPG, gasoline, naphtha), middle distillates (kerosene, jet fuel, diesel), heavy distillates and residuum (heavy fuel oil, lubricating oils, wax, asphalt) [4]. Owing to the importance of petroleum products in consumers' budgets and the economy, the price of these products is of acute interest to the public and to policy makers. Crude oil prices continue to be the main driver of petroleum products prices and there is a remarkable relationship between the prices of crude oil and its petroleum products prices [5]. The movement of crude oil price can affect not only the consumption and production expenditures, but also future investment decisions. Since 1989, economists have conducted several researches on how crude oil and products prices more especially gasoline prices adjust over time. Most of these studies examine the relationship between prices of crude oil and products' prices based on linear causality relationship and Vector Error Correction Model (VECM) modeling that show there is unidirectional causality from the price of crude oil to that of gasoline. Crude oil being the principal input in the production of gasoline, one would expect crude-oil prices to be a primary determinant of gasoline prices. [6], for instance studied the dynamic relationships between crude oil prices and US gasoline prices from the year 1973 to 1987; he came to a concession that the US gasoline price is mainly influenced by the price of crude oil. [7], explored the price relationship between crude oil and U.K. fuel over the period 1981-1989 and found a long-run relationship in retail fuel price response to changes in crude oil price.

[8], examined whether an asymmetric response to unanticipated positive and negative crude cost shocks could be identified in Canadian retail gasoline price using weekly data for thirteen cities from 1990 to 1996. Using the Threshold Autoregressive model, they failed to find asymmetric response of gasoline prices to changes in crude oil prices and further suggested that the reason for the different result was related to differences in market structure, in dataset, and in the methodology. [9] focused on the German and French heating oil market and attempted to link them via cointegration techniques to Brent prices and the respective currency to USD exchange rates. The research was conducted for the period January 1987 to December 1997. The results obtained confirmed the existence of a long-run relationship between the price series. [10] employed cointegration and ECM to investigate the relationship between the prices of crude oil and product price dynamics using weekly and monthly data for the period running from 1994 to 2002 taking into account four distinct market areas (Mediterranean, Northwestern Europe, Latin America, and North America). Empirical evidence showed that product prices are statistically relevant in explaining short- and long-run adjustment in petroleum markets. [11] also found a strong positive

correlation of 93% between the gasoline prices and oil prices in the 2007 to 2009 period. In recent papers, [12] [13] [14] [15] and [16] among others have all researched into the price relationship between crude oil and its products in various fuel markets. Most of the above studies done on individual markets considered only the response of gasoline prices to changes in crude oil prices. That notwithstanding, none of these studies has been extended to the Ghanaian fuel market. In the present paper, we study the relationship between crude oil prices and retail fuel prices (Gasoline, Gas oil, Residual fuel oil and Premix fuel) in Ghana. This was done in order to assess whether a change in crude oil will be transmitted to the pump fuel prices on the Ghanaian fuel market.

2. Research Method

The Unit-root tests were used to determine whether the time series was stationary or non-stationary [17]. A time series data is called stationary if its value tends to revert to its long-run average value and properties of data series are not affected by the change in time [17]. The Augmented Dickey Fuller approach (ADF) and the Phillips Perron (PP) tests were used to test the hypothesis of the unit root of the series. The ADF test consists of estimating the following regression model:

$$y_t = c + \beta_t + \alpha y_{t-1} + f_1 \Delta Y_{t-1} + f_2 \Delta Y_{t-2} + \cdots + f_p \Delta Y_{t-p} + \varepsilon_t \quad (1)$$

where

$y(t-1)$ = lag1 of the time series, ΔY_{t-p} = first difference of the series at time $t-p$ and ε_t is a pure white noise error.

The test statistic for the ADF test is given by $t_{\theta=0} = \frac{\hat{\theta}}{\sigma(\hat{\theta})}$ where $\hat{\theta}$ is the OLS estimate of θ and $\sigma(\hat{\theta})$ is the standard error of the estimate. We note that $\theta = 0$ indicate existence of a unit root in Equation (1). The cointegration analysis was used to evaluate the co-movement of a long-term asset price within an equilibrium model. It established a long-term relationship by calculating long-run equilibrium asset prices. Two or more time series cointegrated when they each possess a unit root and a linear combination of the variables is a stationary process. This work employed the ARDL approach in establishing the long run relationship between the prices of crude oil and its products. The advantage of the ARDL approach is that while other cointegration techniques require all of the regressors to be integrated of the same order; the ARDL approach can be applied whether the repressors are $I(1)$ or $I(0)$. This means that the ARDL approach avoids the pre-testing problems associated with standard cointegration, which requires that the variables be already classified into $I(1)$ or $I(0)$ [18]. Also, the ARDL model is the more statistically significant approach to determine the cointegration relation in small samples [19]. As the long run relationship between the prices of crude oil and petroleum products in Ghana is studied, the following unrestricted error correction model (UECM) is selected for the ARDL bounds testing:

$$\Delta \ln GS_t = \beta_0 + \sum_{i=1}^{q} \alpha_1 \Delta \ln GS_{t-i} + \sum_{i=1}^{p_1} \beta_1 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_1 \Delta \ln EXR_{t-i} + \sum_{i=1}^{p_3} \gamma_1 \Delta \ln INF_{t-i} + \lambda_1 \ln GS_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} + \lambda_4 \ln INF_{t-1} + \mu_t \quad (2)$$

$$\Delta \ln GO_t = \beta_0 + \sum_{i=1}^{q} \alpha_2 \Delta \ln GO_{t-i} + \sum_{i=1}^{p_1} \beta_2 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_2 \Delta \ln EXR_{t-i} + \sum_{i=1}^{p_3} \gamma_2 \Delta \ln INF_{t-i} + \lambda_1 \ln GO_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} + \lambda_4 \ln INF_{t-1} + \mu_t \quad (3)$$

$$\Delta \ln RFO_t = \beta_0 + \sum_{i=1}^{q} \alpha_3 \Delta \ln RFO_{t-i} + \sum_{i=1}^{p_1} \beta_3 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_3 \Delta \ln EXR_{t-i} + \sum_{i=1}^{p_3} \gamma_1 \Delta \ln INF_{t-i} + \lambda_1 \ln RFO_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} + \lambda_4 \ln INF_{t-1} + \mu_t \quad (4)$$

$$\Delta \ln PR_t = \beta_0 + \sum_{i=1}^{q} \alpha_1 \Delta \ln PR_{t-i} + \sum_{i=1}^{p_1} \beta_1 \Delta \ln CRD_{t-i} + \sum_{i=1}^{p_2} \chi_1 \Delta \ln EXR_{t-i} + \sum_{i=1}^{p_3} \gamma_1 \Delta \ln INF_{t-i} + \lambda_1 \ln PR_{t-1} + \lambda_2 \ln CRD_{t-1} + \lambda_3 \ln EXR_{t-1} + \lambda_4 \ln INF_{t-1} + \mu_t \quad (5)$$

where Δ is the first difference operator, μ represents the white noise error term, GS represents Gasoline, GO represents Gas oil, RFO represents Residual Fuel oil, PR represents Premix, CRD represents Crude oil, EXR represents Exchange rate and INF represents Inflation rate. All variables are in their natural logarithmic form. For the long-run coefficients, models ARDL (p, q_1, q_2, q_3) as listed in Equations (6)-(8) are employed:

$$LNGS_t = c_1 + \sum_{i=1}^{p} \alpha_1 LNGS_{t-i} + \sum_{i=0}^{q_1} \beta_1 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_1 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_1 LNINF_{t-i} \quad (6)$$

$$LNGO_t = c_2 + \sum_{i=1}^{p} \alpha_2 LNGO_{t-i} + \sum_{i=0}^{q_1} \beta_2 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_2 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_2 LNINF_{t-i} \quad (7)$$

$$LNRFO_t = c_3 + \sum_{i=1}^{p} \alpha_3 LNRFO_{t-i} + \sum_{i=0}^{q_1} \beta_3 LNCRD_{t-i} + \sum_{i=0}^{q_2} \lambda_3 LNEXR_{t-i} + \sum_{i=0}^{q_3} \gamma_3 LNINF_{t-i} \quad (8)$$

where $\alpha, \beta, \lambda, \gamma$ are the long-run multipliers. The lag orders p, q_1, q_2 and q_3 are selected by Bayesian Information Criteria (BIC). The short-run dynamic coefficients are obtained by the corresponding ECM model as Equations (9)-(11):

$$\Delta \text{LNGS}_t = c_1 + \sum_{i=1}^{p} \alpha_1 \Delta \text{LNGS}_{t-i} + \sum_{i=0}^{q_1} \beta_1 \Delta \text{LNCRD}_{t-i} + \sum_{i=0}^{q_2} \lambda_1 \Delta \text{LNEXR}_{t-i} + \sum_{i=0}^{q_3} \gamma_1 \Delta \text{LNINF}_{t-i} + \varepsilon_1 \text{ECM}_{t-1} + \mu_{1t} \quad (9)$$

$$\Delta \text{LNGO}_t = c_2 + \sum_{i=1}^{p} \alpha_2 \Delta \text{LNGO}_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta \text{LNCRD}_{t-i} + \sum_{i=0}^{q_2} \lambda_2 \Delta \text{LNEXR}_{t-i} + \sum_{i=0}^{q_3} \gamma_2 \Delta \text{LNINF}_{t-i} + \varepsilon_2 \text{ECM}_{t-1} + \mu_{2t} \quad (10)$$

$$\Delta \text{LNRFO}_t = c_3 + \sum_{i=1}^{p} \alpha_3 \Delta \text{LNRFO}_{t-i} + \sum_{i=0}^{q_1} \beta_3 \Delta \text{LNCRD}_{t-i} + \sum_{i=0}^{q_2} \lambda_3 \Delta \text{LNEXR}_{t-i} + \sum_{i=0}^{q_3} \gamma_3 \Delta \text{LNINF}_{t-i} + \varepsilon_3 \text{ECM}_{t-1} + \mu_{3t} \quad (11)$$

where $\alpha, \beta, \lambda, \gamma$ are the short-run coefficients, ε is the error correction term which is the speed of adjustment from which the prices of the petroleum products returns to equilibrium after adjustment in crude oil prices, exchange rate and inflation rate.

3. Results and Discussions

Results from both the ADF and the PP test as indicated in **Table 1** showed that the prices of Crude oil, Gasoline, Gas oil, Residual Fuel Oil and Premix are all not stationary at level but stationary at the first difference. "**" in **Table 1** denotes rejection of the null hypothesis at the 1% significance level.

Results from the ARDL bounds test for cointegration showed the presence of cointegration among the prices of Crude oil and the prices of Gasoline, Gas oil and RFO but failed to reject the null hypothesis of no cointegration between the prices of Crude oil and Premix fuel. From **Table 2**, the F-statistic (5.92, 11.24 and 5.27) of Gasoline, Gas Oil and RFO respectively clearly exceeds both the lower and upper bounds at the 5% significance level which confirms the existence of a long run relation among the prices of Crude oil and Gasoline, Gas Oil and RFO. The F-statistic (3.89) of Premix falls below the upper bound at the 5% significance level, nullifying the existence of a long run relationship among the prices of Crude oil and the prices of Premix.

Table 1. Unit root test.

	Level		First Difference	
Variable	**ADF**	**PP**	**ADF**	**PP**
Crude oil	−1.874	−1.503	8.124**	−7.978**
Gasoline	−2.558	−2.596	10.692**	10.684**
Gas oil	−2.713	−3.079	14.992**	15.745**
RFO	−1.490	−1.144	−6.996**	−6.960**
Premix	−2.778	−2.177	−5.912**	−8.687**
Exchange rate	−0.058	−0.304	−7.393**	−7.311**
Inflation rate	0.808	0.828	−8.258**	−8.258**

Table 2. Autoregressive distributed lag bounds test.

	Gasoline	Gas oil	RFO	Premix
F-Statistics	5.92	11.24	5.27	3.89
5% lower bound	4.94	3.23	3.23	3.23
5% upper bound	5.73	4.35	4.35	4.35
Remark	Long run relationship exists	Long run relationship exists	Long run relationship exists	No long run relationship exists

The ARDL-ECM were selected based on the Schwarz Bayesian Criteria. The information criteria estimated 500 different ARDL models and out of the 500 models, the ARDL (1, 0, 1, 0) ARDL (1, 0, 0, 0) and the ARDL (2, 0, 2, 0) were found to be the models with the least information lost thereby becoming the best models for Gasoline, Gas oil and RFO respectively. Figures 1-3 show the graphical representation of the Schwarz Criteria selection focusing on the top 20 models with respect to the minimal information lost.

3.1. Long Run and Short Run Estimates

The results obtained from the Long run and the Short run estimation of the ARDL Error Correction Model (ECM) for the prices of Crude oil and petroleum products are presented in Table 3 and Table 4 respectively. The error correction coefficients were negative and significant as desired showing the direction and speed of adjustment towards the long run equilibrium. The negative sign implies that, in the absence of disparity in the independent variables, a shift of the previous months deviation from the long run is corrected in the current period at adjusted speeds of −0.172125, −0.488370 and −0.179091, representing error correction coefficients of Gasoline, Gas oil and RFO respectively. The results from the estimates of the error correction model, the prices of Crude oil, exchange rate and inflation rate affect the prices of petroleum products in Ghana in a unique way in both the short run and the long run. It is evident from the results that the prices of crude oil have a positive and significant effect on the prices of Gasoline, Gas oil and RFO. Hence, an increment in the prices of crude oil increases the prices of Gasoline, Gas oil and RFO and thus a decrease in the prices of crude oil decreases the prices of Gasoline, Gas oil and RFO in both the long and the short run. Exchange rate on the other hand has a negative and significant effect on the prices of Gasoline, Gas oil and RFO in both the short and the long run. This is so because, an increment in a country's exchange rate implies a high purchasing power of the country. Hence an increment in the exchange rate decreases the amount of money needed to be payed to purchase crude oil for the production of petroleum products in Ghana and the vice versa in both the short and the long run. Inflation rate has a significant and positive effect on only the prices of Residual fuel oil in both the short and long run since most of the RFO produced in the country is exported. Hence foreigners need to pay more when inflation goes up and less when inflation goes down. It can also be inferred that, RFO is affected the lag of itself and exchange rate in the short run. The coefficient of inflation for the prices of Gasoline and Gas oil were positive and negative respectively but were however insignificant even at 10% level, implying that, all things being equal, changes in the rate of inflation does not affect the prices of Gasoline and Gas oil in Ghana.

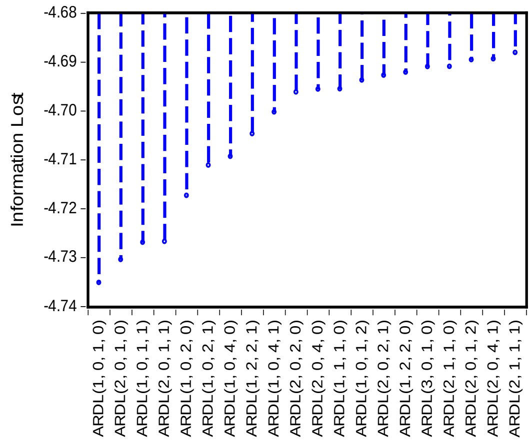

Figure 1. ARDL-ECM model for Gasoline.

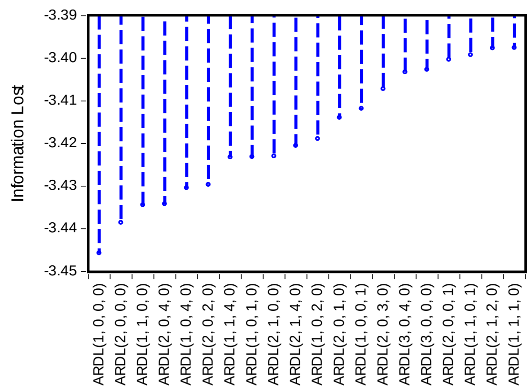

Figure 2. ARDL-ECM model for Gas oil.

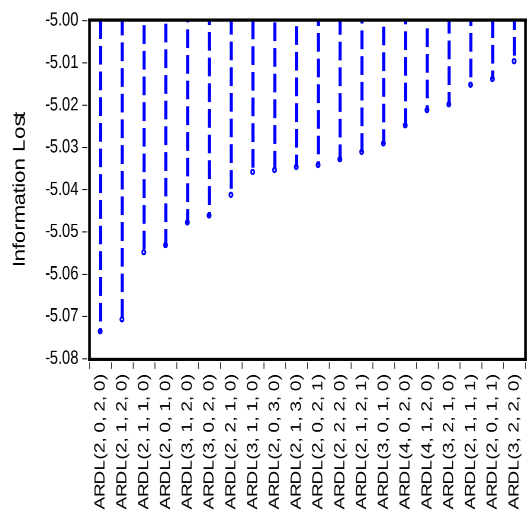

Figure 3. ARDL-ECM model for RFO.

Table 3. Results for the short run estimate.

Variable	Model 1 (Gasoline)	Model 2 (Gas oil)	Model 3 (RFO)
D(PP(−1))	---	---	0.312434 (0.079291) [3.940328]
D(LNCRD)	0.085429* (0.027293) [3.130070]	0.178000* (0.046941) [3.791989]	0.133713* (0.030350) [4.405708]
D(LNEXR)	−0.876944* (0.170659) [−5.138571]	−0.122831* (0.034801) [0.034801]	−0.958431* (0.180677) [−5.304675]
D(LNEXR(−1))	---	---	0.303154 (0.198790) [1.524995]
D(LNINF)	0.015811 (0.020601) [0.767507]	−0.034775 (0.037981) [−0.915578]	0.066610* (0.022876) [2.911775]
CointEq(−1) ϕ	−0.172125* (0.051912) [−3.315680]	−0.488370* (0.077285) [−6.319067]	−0.179091* (0.032252) [−5.552807]

Table 4. Results from the long run estimates.

	Model 1 (Gasoline)	Model 2 (Gas oil)	Model 3 (RFO)
LNCRD	0.496323* (0.125394) [3.958124]	0.364479* (0.076352) [4.773654]	0.746618* (0.128562) [5.807475]
LNEXR	−0.338945* (0.102727) [−3.299486]	−0.251513* (0.060751) [−4.140072]	−0.956048* (0.100838) [−9.481029]
LNINF	0.091860 (0.128141) [0.716868]	−0.071205 (0.076927) [−0.925624]	0.371933* (0.124469) [2.988169]
C	−1.111401* (0.357072) [−3.112541]	−0.700362* (0.216763) [−3.231012]	−2.112110* (0.363466) [−5.811028]

3.2. Diagnostic Test

In other to validate that the ARDL-ECM developed has a good predictive relationship, regression diagnostics are used. The ARDL-ECM Residual Serial Correlation LM test indicated that there is no serial correlation problem in the estimation. The heteroskedasticity tests with the Chi-squared statistic also specified that heteroskedasticity is eliminated from the data. Results from serial correlation and heteroskedasticity tests are presented in **Table 5**. The cumulative sum (CUSUM) tests were also employed to verify the stability of the parameters in the Error Correction Model [20]. The result is shown in **Figures 4-6**. The CUSUM plots in **Figures 4-6** lie within the critical bounds at the 5 percent significance level, which confirms the stability of the parameters. Accordingly, the models and their corresponding parameters for the prices of crude oil and its products in Ghana are reliable.

Table 5. Heteroskedasticity tests.

	Model 1 (Gasoline)	Model 2 (Gas oil)	Model 3 (RFO)
LM-Statistics	2.308815 (0.1313)	4.999141 (0.2480)	3.816142 (0.0532)
Chi-Square Statistics	0.077411 (0.7791)	1.169994 (0.3013)	0.451846 (0.8754)

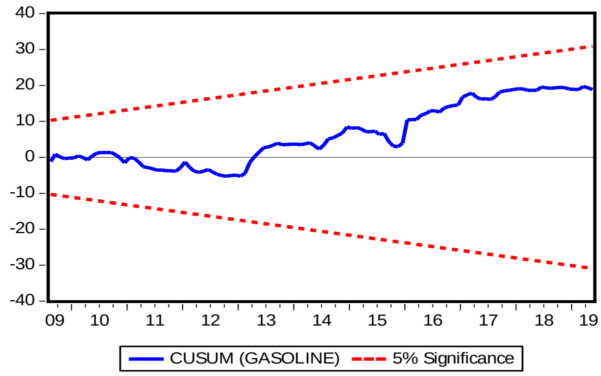

Figure 4. CUSUM plots residuals for Gasoline.

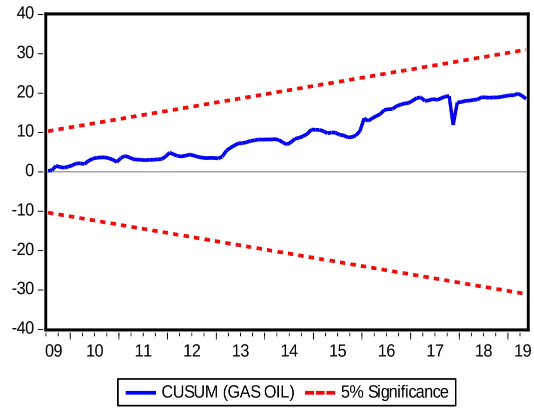

Figure 5. CUSUM plots residuals for Gas oil.

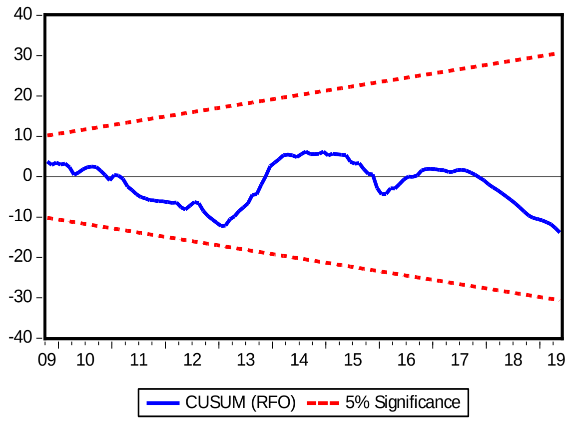

Figure 6. CUSUM plots residuals for RFO.

4. Conclusion

The research examined the long run relationship between the prices of crude oil and petroleum products in Ghana. Results from the cointegration analysis showed the long-run relationship between the prices of crude oil and Gasoline, Gas oil and Residual fuel oil. The prices of crude oil showed no long run relationship with the prices of Premix fuel. However, prices of crude oil showed significant short and long run relationship on the prices of Gasoline, Gas oil and Residual fuel oil. Exchange rate also showed negative significant short and long run relationship on the prices of Gasoline, Gasoil and Residual fuel oil. Inflation has a significant relationship on only the prices of Residual fuel oil in both the short and the long run.

Conflicts of Interest

The research work titled Cointegration Analysis of the Relationship between the Prices of Crude Oil and its Petroleum Products in Ghana was conducted by the three authors Brew, L., Belinda, E. K (student), and Wiah, E.N. without any assistance from any place. We the authors do hereby declare that there is no conflict of interest with respect to the publication of this paper. No legal or financial assistance was sought from any organisation or our employer. We the authors did everything on our own as a way of contributing to the promotion of knowledge. The writing and editing were conducted by the authors themselves. We are seeking for the publication of this article as staff of University of Mines and Technology, Tarkwa, Ghana. With regards to the availability of the data, the National Petroleum Authority (NPA) only permitted us to use the data for our research publication.

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