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Article

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Are Oil Prices Mean Reverting? Evidence from Unit Root Tests with Sharp and Smooth Breaks

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ABSTRACT

This study examined the validity of efficiency market hypothesis for the oil market by employing a novel Fourier unit root test that accounts for sharp shifts and smooth breaks based on daily data. Our results established the existence of structural shifts and nonlinearity in the oil market indices suggesting that oil market is inefficient when structural breaks is calibrated into the model. Unlike results obtained from existing traditional unit root test, results from sharp shifts and smooth breaks unit root test suggests the rejection of unit root null for each of the oil indices. The study has some practical and policy implications based on our findings.

Keywords: Oil Prices, Market Efficiency, Fourier Analysis, Unit Root Tests, Energy
JEL Classifications: C22, C50, G10, G12

1. INTRODUCTION

Over the years the (Fama, 1970) efficient market hypothesis (EMH) has been used to determine whether or not stock market is efficient. According to the narrative, a market is said to be efficient in it weak form if the stock reflects all past publicly available information[1]. Statistically, this implies that its series are non-stationary, follows a random walk and unpredictable (Westerlund and Narayan, 2014); (Sensoy and Tabak, 2016); (Lawal et al., 2018); (Lawal et al., 2018); (Aun et al., 2016); (Tuyon and Ahmad, 2016); (Babajide et al., 2016a); (Babajide et al., 2016b); (Salisu et al., 2018);(Babajide et al., 2015); (Lawal, 2014); (Lawal et al., 2018); (Lawal et al., 2015); (Salisu et al., 2016); (Kumar and Kyophilavong, 2014); (Auer, 2016); (Huang et al., 2018); (Almail and Almudhaf, 2017)[2]. In the recent, the hypothesis has been extended to other assets order than stock market see for instance (Charles et al., 2015); (Kuruppuarachchi et al., 2017); (Linder, 2018); (Narayan and Sharma, 2018); (Tursoy and Faisal, 2018) for commodity prices; Søren Fiig (2016) for pension fund; (Bouri et al., 2017) for wine market efficiency; (Fender et al., 2012); (Agur et al., 2018) for sovereignty bond; (Chiang et al., 2010); (Mensah et al., 2017); (Al-Khazali et al., 2012); (Mei-se et al., 2018); (Volkov and Yuhn, 2016); (Wen et al., 2018); (Swaray and Salisu, 2018) for exchange rate among others.

Whether or not a market follow a random walk has some policy implication for instance, inefficient market provides arbitrage opportunities, aids growths among others (Lawal et al., 2017);

1 Recently a school of thought emerged in financial economics that stresses that RWH is not a necessary and sufficient condition for efficient market hypothesis (Charfeddine and Ben, 2016) but they were not able to established an alternative platform to determining efficiency.

2 Another school of thought (Charles et al., 2017); (Almail and Almudhaf, 2017); (Ramírez et al., 2015); (Urquhart and McGroarty, 2016) are of the view that efficient market is not statistics as it evolves overtime i.e., calibrating time varying proponent and market adaptability into the theory of market hypothesis.

(Lawal et al., 2018); (Lawal et al., 2016) (Wang et al., 2015); (Dedeo and Kaya, 2014); (Guo et al., 2016). Thus, the results of efficiency nature of market prices provides significant usage to various economic agents for instance hedgers, brokers and other private investors (institutional or individual) will find the results obtain useful in knowing what strategy - contrarian or …. investment strategy to adopt when formulating investment decision. Policy makers will know what policy to manipulate to advance the economy using information on the nature of the market efficiency.

We extend the extent literature by calibrating energy prices behavior with a focus on oil prices into the test on EMHs. Our choice of oil prices among other energy prices is informed by the strategic role oil plays among energy alternatives[3], cum with the recent development in the oil sector of the global economy. Over the years there has been notable surge in oil demand globally. For instance, global oil consumption as at the end of year 2000 stood at about 26.56 billion barrels per annum. It increased to about 32 billion barrels in 2012 and to about 98.48 million barrels per day in the year 2017 (Energy information Administration [EIA] (2018). In tandem with the elementary law of demand and supply viz-a-viz, pricing; the increase in oil demand is followed by corresponding increase in prices of oil. For instance oil price, which stood at $1.63 in 1946 rose to $13.10 in 1976, $37.42 in 1980, $14.44 in 1986, $64.20 in 2007, $85.60 in 2014 and $72 per barrel in 2018. The increase in demand followed by increase in prices have some policies implications, for instance, while oil exporting economics earns more revenue resulting from the increase in prices, oil importing economies like China, Pakistan, India among others spent fortune in securing oil.

Concerted efforts have been put in place by oil importing economies to reduce the consumption of oil, for instance automobile firms are compelled to comply with the Corporate Average Fuel Economy framework aim to reducing the rate of oil consumption by automobiles. In a related the development, the introduction of the compulsory renewable portfolio framework mandating utilities to produce or buy a minimum level of renewable energy essentially aimed at reducing the consumption of fossil fuels (oil). Furthermore, recent, development in technology resulting in development of electric cars and other innovating raises questions on future of oil markets. Other factors that impacts on the predictability of oil prices includes exchange rate fluctuating, speculative trading, decision making of large oil organizations like OPEC; geopolitics among others (Chai et al., 2018; Khan, 2017).

Given the above sceneries, it is important to examine whether or not policies put in place to reduce global oil consumption will have a significant effect on oil price efficiency framework. As earlier stated, if oil price follows a random walk, then changes or shock to oil prices resulted from fall in demand owing to policy changes will have a permanent effect on oil, however, when evidence of mean reverting is established, then oil prices is inefficient and shocks resulting from policies changes is temporary, suggesting existence of arbitrage opportunities in the oil price market.

3 Oil account for about 40% of the world energy mix (BP Statistical Review of world energy, 2013; Solarin and Lean, 2016)

For shadowing our results, evidence abound to show that for all the series, oil prices are mean reverting, suggesting that shocks to the prices is temporary and will naturally adjust back to equilibrium overtime. The reminder of the studies is as follows; section two deals with literature reviews, section three discuss the methodology; section four presents the results and discussion while section five concludes the study.

2. LITERATURE REVIEW

Recent debate on energy studies centers on prediction or forecasting of energy prices, methodological and data mining with few studies on efficiency. Similarly, bulk of the studies on energy efficiency focuses on electricity (Charles et al., 2017); (Almail and Almudhaf, 2017); (Ramírez et al., 2015); (Mcgregor, 2017) alternative sources of energy (Apergis and Vouzavalis, 2018); (Ready, 2018); (Shah et al., 2018); (Huang et al., 2018); (Polanco et al., 2018); (Safari and Davallou, 2018); (Cuestas and Gil-Alana, 2018) disaggregated energy sources. A few others focused on the effect of energy shocks on macroeconomic variables for instance (Volkov and Yuhn, 2016) examined the effects of oil price shocks on exchange rate fluctuation in five major oil-export economics of Russia, Brazil, Mexico, Canada and Norway and observed that the asymmetric behavior of exchange rate volatility in the studied economies is essentially driven by the efficiency of financial markets rather than the impact of oil proceeds in studied economy.

Similarly, (Swaray and Salisu, 2018) examined the link between stock prices of non-integrated firms in both the upstream and downstream sectors of the global oil supply chain as it relates to fluctuations in oil prices using a panel autoregressive distributed lag technique. The study observed that movement in stock prices of the two streams are in opposite directions, with each sector responding differently to episodic changes in market conditions arising from the global financial crisis. Swaray and Salisu's finding contradicts that of (Wen et al., 2018) who noted that China's 2013 oil product pricing reform has significantly reduce the risk associated with stock market investments and financing (Adedapo et al., 2017); (Javid et al., 2018).

(Nademi and Nademi, 2018) employed semiparametic Markov switching AR-ARCH model to forecast the price of OPEC, West Texas Intermediate (WTI) and Brent crude oils focusing on the applicability of this model in line with the proper selection of the core function in the prediction of the crude oil prices. The study also employed ARIMA and GARCH models and observed that evidence of mean reverting cannot be established when ARIMA and GARCH models are employed.

Focusing on persistency, endogeneity and heteroskedasticity, (Han et al., 2017) employed a novel hybrid approach as well as (Westerlund and Narayan, 2014); (Narayan et al., 2016) estimation techniques to examine the efficiency or otherwise of crude oil prices within the context of investors' intention based on data sourced from the Google search volume index. The study observed that investor's attention induces efficiency.

Miao et al. (2017) examined the factors that influences efficiency pricing in crude oil price using a number of forecasting models such as no-change forecast, EIA forecast, future based forecast, factor-based, stepwise regression, LASSO model, Pesaran-Timmermann test techniques. The study considered six categories of influential factors viz-supply, demand, financial market, commodity market, speculative and geopolitical. It observed that LASSO forecast is key in driving market efficiency (Huang et al., 2017).

For the Australian economy, (Valadkhani and Smyth, 2018) employed asymmetry in the coefficients of a normalized beta weighting function within an Asymmetric Mixed Data Sampling model in order to access the impact of both the timing and the lagged marginal effects of a change in retail petrol prices as it response to a change in oil prices. The study observed existence of asymmetries in both the timing and magnitude of retail petrol prices to a change in the oil prices. The study concluded that asymmetries in both the oil prices and retail prices are key drivers of the prediction of the magnitude of oil price.

In a related development, (Badeeb and Lean, 2018) extend literature by examining the impact of Islamic sectorial stock on oil predictability using non-linear autoregressive distributed lag co-integration method, so as to capture simultaneously the short and long run asymmetries through both the positive and negative oil price shocks. The results show that Islamic sectorial stock shocks is weak in driving oil price predictability.

Chai et al. (2018) employed a number of estimation techniques that calibrates change points, regime-switching, time-varying determinants, and trend decomposition of high frequency and non-linearity properties to examine the efficiency nature of the WTI crude oil prices. Some of the techniques employed include Product Partition Model-K-Means, time-varying transition probability, Markov regime switching, Bayesian model average and the time-varying parameter structure time series model. The study observed the evidence abound to show that WTI is inefficient and predictable.

Funk (2018) extends Chai et al. (2018) model by employing the use of both the mean squared prediction error (MSPE) and VAR model to examine the predictability and efficiency of Brent crude oil. Unlike (Chai et al., 2018) that focused on WTI prices, (Funk, 2018) examined efficiency of the Brent Crude oil arguing that the latter is the new benchmark that central bankers monitor and predict, given the fact that the former has suffered from structural instability as it reflects only US economy outlook as against global oil market dynamics since the 2010/2011. The study observed that efficiency in the Brent oil price is better construct for horizons up to 24 months with gains in the MSPE ratio as high as 25%.

Worried by the inability of the traditional metrics such as energy return on investment owning to system boundaries and failure to described labour and physical capital relating to energy BUUS (2017) employed the price of energy model and cost of efficiency matrix model to investigate the nature of energy price efficiency. The study observed that the average useable energy output and average useable energy input are the key drivers of energy efficiency.

Weijermars and Sun (2018) investigated the existence or otherwise of mean reversion price scenarios base on historic oil price using data from 1861 to 2012 for WTI and Brent. The study employed Black Swan Scenario and observed that the mean reversion price for a given time period corresponds to the marginal cost of supply. It further observed that when there is disequilibrium between the forces of demand and supply, spot prices move in a bandwidth bound at the bottom, by cash cost of supply and at the top by the concurrent price of demand destruction. On the degree of elasticity, the study observed that short term elasticity of demand stood at 0.015 implying high level of inelastic, with long term elasticity of supply moving from high level elastic of 0.99 to low level of 0.37 for the periods 1965–1983 and 1984–2012 respectively. The study concluded that mean reversion framework is often affected by changing development around the Black Swan events which is usually unknown.

3. DATA AND METHODOLOGY

Data for the study comprises of daily market quotes for the three world largest oil prices: WTI; OPEC oil prices index; and the Brent oil prices sourced from 16/06/2006 to 29/12/17. Data for the study was obtained from the US EIA. The study followed (Bahmani-Oskooee et al., 2016) to model mean reversion properties in oil prices using both sharp and smooth breaks using the following equation:

$$y_t = \alpha + \beta t + \sum_{l=1}^{m+1} \theta_l DU_{l,t} + \sum_{l=1}^{m+1} \rho_l DT_{l,t} + \sum_{k=1}^{n} \gamma_{1,k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2,k} \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (1)$$

Where *t, T* and *m* represents time trend, sample size and the optimum number of breaks respectively. We defined the other regressors as follows:

$$DU_{k,t} = \begin{cases} 1 & \text{if} \quad TB_{k-1} < t < TB_k \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

$$DT_{k,t} = \begin{cases} t - TB_{k-1} & \textit{if} \quad TB_{k-1} < t < TB_k \\ 0 & \textit{otherwise} \end{cases} \quad (3)$$

Where *DU* and *DT* capture the sharp shifts. Following Bouri et al. (2017), we employed the Fourier approximation so as to obtain a global approximation of the smooth transition by calibrating $\sum_{k=1}^{n} \gamma_{1,k} \sin\left(\frac{2\pi kt}{T}\right)$ and $\sum_{k=1}^{n} \gamma_{2,k} \cos\left(\frac{2\pi kt}{T}\right)$ into the model. Here and are the number of frequencies with n = T/2, and the particular frequency respectively.

It is important to address issues relating to the choices of *m, n,* and *k*; we restrict $n = 1$, given that $\gamma_{1,k} = \gamma_{2,k} = 0$ can be rejected for one frequency, thus, the null hypothesis of time invariance is rejected as well. This restriction is crucial to saving the degress of freedom and prevent over-fitting. Thus, we redefine equation (1) using $n = 1$ such that:

$$y_t = \alpha + \beta t + \sum_{l=1}^{m+1} \theta_l DU_{l,t} + \sum_{l=1}^{m+1} \rho_l DT_{l,t} + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (4)$$

To remove the effect of possible structural breaks on oil price given the information on break dates, we reconstruct the time series of oil price by calibrating both sharp shifts and smooth breaks as stated in equation (5) such that:

$$y_t = oil_t - \alpha - \beta t - \sum_{l=1}^{m+1} \theta_l DU_{l,t} - \sum_{l=1}^{m+1} \rho_l DT_{l,t} - \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) - \sum_{k=1}^{n} \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (5)$$

Here, y_t represent oil prices adjusted for the effect of both sharp and smooth breaks; oil_t represents the log of oil price.

The above literatures all show clearly a scarcity of literature on the efficiency in the oil price market. Given the important role oil price play in economic world, research on it should be extended to cover its market efficiency, knowing fully that the value added by profitable managers and investment strategies depends on whether or not the market is efficient.

The current study thus intend to contribute to extent literature on market efficiency with focus on the oil price market within the context of random walk hypothesis using a unit root test techniques that accounts for potential sharp shifts and smooth breaks in oil prices. It is a well-established fact in literature that the persistence parameter of a process could be overestimated if we ignore structural breaks from the unit root tests, thus reducing the power to reject a unit root when there is huge potential of stationarity. To overcome this, for the current study, we calibrates the breaks in our unit root testing techniques, with the regime changes being both smooth and sharp thereby capturing both types of structural breaks that likely co-exist. This, feature is not common with existing traditional unit root test techniques like ADF, (Zivot and Andrews, 1992); (Strazicich et al., 2004); (Narayan and Popp, 2010); (Westerlund and Narayan, 2015) among others.

This study is one of the first set of studies that test for efficiency in the three widely used indices of oil prices, by calibrating smooth and sharp breaks into our model.

4. RESULT AND DISCUSSION

Table 1 presents the results of the descriptive statistics of the indices model in our study. From the table, it can be seen that the mean and variance across the three indices are quite similar. Besides, all the indices are skewed to the left. The Jarque-Bera normality test result shows that all the series are non-normally distributed.

Table 1: Descriptive statistics

Statistics/Series	OPEC	WTI	BRENT
Mean±SD	0.0218±0.1388	0.0184±0.986	0.0149±0.0884
Skewness	2.4915	−0.0814	0.2460
Kurtosis	21.018	8.429	5.9684
Jarque-Bera	984.844***	192.488***	99.848***

Source: Authors' computation 2018. SD: Standard deviation

Next we proceeds to test for the efficiency of the oil market, first, be employing conventional linear unit tests namely ADF, Z and A, PP, KPSS among others[4]. From the result, it is evidence that we cannot reject the null of unit root for all the series (Table 2). These techniques do not provide information about structural breaks, besides the results here shows that oil market prices is efficient.

Knowing that neglecting nonlinearity as well as structural changes in the data generating process distort the results towards accepting the null of a unit root, it is expedient to test for nonlinearity and structural changes in the oil prices by employing unit root test with a Fourier function as proposed by (Bahmani-Oskooee et al., 2016). We estimate equation (5) for each integer k = 1 …5, such that a single frequency is used to account for a wide variety of breaks as shown in panel A of Table 3. The significant in Panel A implies that both the sine and cosine terms are essential in the model. The number of lags required to estimate a serial correlation in the residuals are presented in fifth column, it is 3 across all the 3 indices. The results of a unit root test with a nonlinear Fourier function is shown in the last column. From the results, it is evidence that we can reject the unit root null hypothesis for all the indices, implying that oil prices are mean reverting, not characterized by random walk and provides arbitrage opportunities in the oil prices.

Panel B of Table 3 presents the results of the structural breaks. From the results, it is evidence that the series follow mean reverting process. In other words, we are able to reject the null hypothesis for all the three indices. The results of the date breaks coincide with some important event in the global economy that may likely affect the behavior of oil prices. For instance, the date breaks in the early 2000s to mid-2008 is largely due to increase in real oil price facilitated by a series of positive aggregate demand shocks motivated by shifts in global economic activities, the falling value of US dollar, geopolitical activities and natural disasters such as North Korean missiles tests, 2006 Israel-Lebanon conflicts, Iranian nuclear threat, Hurricane Katrina, among others. The breaks in the 2011 through 2014 coincides with a series of positive oil market-specific demand shocks, majority owing to political instability in the Middle East, sharp rise in investors demand as a response to the unfolding global financial crises. The breaks in 2014–2017 is characterized by the surge in oil prices impulse relationship with events relating to the analysis of global oil production, global real economic activities and real price of emerging alternative sources of energy, soaring demand in China, reports showing a decline in petroleum reserves, uncertainty around peak oil characterized by a significant fall from a peak of $147/b in July, 2008 to $32/b in December, 2008 and emerging surge to $120/b in November, 2014, financial speculation.

4 Both at constant and constant trend.

Table 2: Univariate unit root tests results

Indices	Levels			First difference		
	ADF	PP	KPSS	ADF	PP	KPSS
OPEC	−1.4892 (3)	−0.5841 [3]	1.8441 [9]**	−0.7301 (2)	−7.8211 [7]	0.4216 [7]
WTI	−0.8929 (3)	−1.3421 [4]	1.4218 [9]	−5.9211 (2)**	−9.7511 [7]	0.1641 [7]
Brent	−0.6562 (3)	−2.3814 [3]	1.1924 [9]**	−10.8294 (2)	−11.2114 [7]	0.2773 [5]

Source: Authors' computation 2018. *,**,*** implies 0.1, 0.05, 0.01 levels of significance respectively. () Indicates the truncation for Bartlett kernel as recommended by (Newey, 1987), while [] implies the lag order selected based on the recursive statistics as recommended by (Perron, 1989)

Table 3: Fourier unit root test

Panel A: Results of the LM unit root test					
Indices	SSR	$\hat{k}$	$F(\hat{k})$	The number of lag Δyt	$\tau_{LM}(\hat{k})$
OPEC	3.8742	1	12.8416***	6	−56.7821***
WTI	1.6284	1	14.8483***	4	−49.8411***
BRENT	1.8941	1	13.9418***	8	−36.9811***
Panel B: Results of the sharp drifts (breaks) dates in equation (5)					
Indices	Sup_{FT}	T_i	Regime dates		$\tilde{c}$
OPEC	13.018***	2008	7/08/2008		1.008***
		2011	24/01/2011		1.021***
		2016	4/01/2016		1.060***
WTI	11.091***	2006	15/07/2006		1.033***
		2008	08/07/2008		1.065***
		2014	04/05/2014		1.011***
BRENT	8.946***	2008	07/08/2008		1.0611***
		2011	03/07/2011		1.0221***
		2014	04/05/2014		1.0241***

Source: Authors' Computation 2018. SSR: Sum of square residuals

5. CONCLUSION

The essence of this study is to examine the validity of EMHs in the energy sub-sector of the global economic with a focus on oil price indices. The study employed a novel Fourier approximation unit root test techniques that account for both sharp shifts and smooth breaks in the series to analysis data oil prices series of the three major oil indices - OPEC, WTI and Brent. We first employed the traditional unit root tests like ADF, PP, and KSPP among others and observed that oil price indices follow a random walk, in other words, efficient.

The results from our Fourier analysis show that for all the series we cannot reject the null of unit root test. It further provides evidence of structural break dates which coincides with significant events in the global oil markets. It also shows evidence of nonlinearity in the date, thus validating the choice of Fourier techniques, calibration of both sharp and smooth structural breaks knowing fully that failure to do so may lead to misleading conclusion that oil market prices follows a unit root process.

Our result have some policy implications to the various economic agents for instance, establishment of the fact that oil prices follows a mean reverting process suggests that arbitrage opportunities exist in the market. This implies that the existence of asymmetric information will allow any investor to make excess return by beating the market through the adopting of a contrarian investment strategy. Market inefficiency also imply that not all public available information are reflected in pricing system, suggesting the need for market regulators to formulate policies that will timely improve investors access to quality information, this will help in avoiding mispricing, bubbles, crashes among others.

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