Long Term Co-dependencies and Long Run Non Periodic Co-cycles among Major Oil Indices: A Fractional Time Series Approach

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ABSTRACT

This research paper employs fractional cointegration analysis to test the long run relationship between and among the spot crude oil prices of the United States West Texas Intermediate (US WTI), Europe BRENT and the Organization of Petroleum Exporting Countries (OPEC). Results revealed that during the study period (3rd January 1997 to 20th March 2009), the distinct natural logarithms of the weekly spot oil prices of the three indices are integrated of order one, but their long run relationship will have a fractionally co-integrated structure. This indicates the deviation from the equilibrium is long lasting and the process responses to the shocks more slowly than in the standard cointegrated system. Moreover, this study examines the fractional cointegration in terms of bi-variate models as well as incorporating all three indices. In both criterions all the cointegration models were identified as fractional processes. Additionally, the fractional cointegrated model corresponds to the Europe BRENT versus the OPEC is more persistence than the bi-variate models considered, and the model of the OPEC versus the Europe BRENT and the US WTI is more persistence when all three markets are considered. Therefore, the behavior or the market movements of an oil index is reflected or transferred to the other markets subsequently in the long run.

Keywords: Fractional co-integration, Gaussian semi-parametric method, Long memory, Spectral regression

INTRODUCTION

Crude oil price is a prime factor which affects directly and indirectly to the health of an economy. It directly affects to the performance of an economy in terms of currency management, interest rates, inflation rates and ultimately to the productivity levels of a nation as a whole, where indirectly affects to all the human beings and it will cause to alterations in the life styles, the way of consumptions and in the long run it affects to the demand and supply chain in all forms. Indeed it has become a thriving force to changes in all the economies in the world. Therefore, there is a high impact to a nation or to the economy as whole with the high level of oil price fluctuations. In fact, the price escalations of oil adversely affect to an economy and make the economy vulnerable to deterioration at most.

There are number of oil importing destinations exist in the global oil market. For example the United State West Texas Intermediate (US WTI), the Europe BRENT, the Organization of the Petroleum Exporting Countries (OPEC), the Dubai market, the Mediterranean market, the Singapore market, etc. These oil markets functions in different geographical areas and with different standards and legislations. However, in the world there are only few oil markets or indices which act as benchmark sources of oil pricing. Mainly they are three such markets: the US WTI, the Europe BRENT and the OPEC. Therefore, oil importing countries can access to these markets which are operated in three distinct geographical areas. In this study these three markets are analyzed to identify if there exist a long term co-dependency among them.

In the literature the fractional cointegration analysis on the **spot crude oil prices** of the three oil indices (US WTI, Europe BRENT and OPEC) could not be found during the study period. The underlying motivation of the research is to identify if there is long term co-dependency among these markets by utilizing fractional cointegration technique. Theoretically, fractional cointegration implies the existence of long run co-dependency and long run non periodic cycles among the indices of interest.

The structure of the paper is as follows. Section 2 presents the materials and methods used for the study. Results and discussions are given in the Section 3 and finally in Section 4 presents conclusions and recommendations of the study.

MATERIALS AND METHODS

The data set consists of weekly spot crude oil prices of the US WTI, Europe BRENT and OPEC for the time period of 3rd January 1997 to 20th March 2009. The data were obtained from the official energy statistics web site of the United States of America (www.eia.doe.gov).

In conventional time series analysis integer order of differencing is used for the purpose of achieving stationarity of a time series. However, later it has found that there exist fractionally integrated models which exhibit long term co-movement of the series and the integer differencing may sometimes be inappropriate (Diebold and Rudebusch, 1989; Cheung and Lai, 1993; Baillie and Bollerslev, 1994; Gil-Alana, 2005).

The implementation of the fractional cointegration technique follows the similar approach of the standard cointegration technique, except that fractional integration process is explored in the residuals series. Initially unit roots tests were performed for the individual time series in order to identify the order and to verify that they all have same order of integration *(d)* as suggested by Engle and Granger (1987). The unit root tests, the Phillips - Perron (PP test; 1988) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS test; 1992) tests, were used simultaneously. In PP test the unit root null hypothesis is tested against the alternative of trend stationarity, while in the KPSS the trend stationarity null hypothesis is tested against the unit root alternative hypothesis. Failure to reject by the PP test and rejection by the KPSS test supports that the series is integrated of order one ($I(1)$). The Engle and Granger method (Engle and Granger, 1987) was used to generate the co-integrating regressions and to obtain the residual series if the series are of same order of integration. The residual series obtained from the co-integrating regressions were then tested for fractional long memory parameter by using Gaussian semi-parametric method (Robinson, 1995). Thus, a fractional process in the residual series implies a long term dependency among the oil indices. The cointegration analysis was carried out firstly considering the bi-variate co-integration systems and followed by a co-integration analysis of all three markets, since they all found to be in the same order of integration.

Fractionally Integrated Process

The general Auto-Regressive Integrated Moving Average process (ARIMA process) is of the form:

$$\phi(L)(1-L)^d(X_t-\mu) = \theta(L)\epsilon_t \quad ; \epsilon_t \sim \text{i.i.d.}(0, \sigma^2) \qquad (1)$$

Where, L is the lag operator, μ is the process mean, $\phi(L) = 1 - \phi_1 L - \ldots - \phi_p L^p$, $\theta(L) = 1 - \theta_1 L - \ldots - \theta_q L^q$, and all roots of $\phi(L)$ and $\theta(L)$ lie out side the unit root circle and d is an integer. In Equation (1), a binomial expansion on $(\tilde{1}L)^d$ can be introduced as the fractional differencing operator (filter):

$$(1-L)^d = \sum_{k=0}^{\infty}(-1)^k \binom{d}{k} L^k$$

$$= 1 - dL + \frac{d(d-1)}{2!}L^2 - \frac{d(d-1)(d-2)}{3!}L^3 + \dots \quad (2)$$

The parameter d is allowed to assume any real value. It will give rise to standard ARIMA process if d is restricted to integer values. The stochastic process X_t is both stationary and invertible if all roots of $\phi(L)$ and $\theta(L)$ lie outside the unit circle (Granger and Joyeux,1980). However, a shock does not have a permanent effect since the process is slowly mean reverting. Assuming that $d \in (0, 0.5)$, Hosking (1981) showed that the correlation function, $\rho(\cdot)$, of an ARFIMA process is proportional to k^{2d-1} as $k \to \infty$. Consequently, the autocorrelations of the ARFIMA process decay hyperbolically to zero as $k \to \infty$ which is contrary to the faster, geometric decay of a stationary ARMA process. Hence, the ARFIMA process is said to exhibit long memory, or long range positive dependence when $d \in (0, 0.5)$. The process exhibits intermediate memory, or long-range negative dependence for $d \in (-0.5, 0)$, and short memory for $d = 0$, corresponding to a stationary and invertible ARMA model. For $d \in (0.5, 1)$, the process is mean reverting, even though it is not covariance stationary, as there is no long run impact of an innovation to future values of the process.

Engle and Granger Test

Engle and Granger (1987) proposed a test for co-integration that is based on an Ordinary Least Squares (OLS) regression. In the Engle and Granger method, one simply performs an OLS regression of one integrated variable on the other integrated variables and then tests the residual series for the long run equilibrium property. Hence, this test performs in two stages. First, estimate an OLS regression on the *I(d)* series and secondly test for the stationarity of the residual time series. If stationarity is found in the residual series, then the model is said to be cointegrated and there exists long run equilibrium among the variables considered.

In the case of $I(1)$ variables x_{1t} and x_{2t}, the Engle and Granger regression is:

$$x_{1t} = c + \beta x_{2t} + \epsilon_t \quad (3)$$

x_{1t} and x_{2t} are cointegrated if and if only if ϵ_t is stationary. Cointegration vector is $(1-\beta)$ and long run equilibrium relationship between x_{1t} and x_{2t} is $x_{1t} = c + \beta x_{2t}$.

In the process of identifying the fractional integration of the residual series it requires to estimate the long memory parameter (*d*). In this study, the estimation of the parameter *d* is done by using the Gaussian semi-parametric estimation procedure (Robinson's test; Robinson, 1995).

The Gaussian Semi-parametric Method

Robinson (1995) developed and proposed a Gaussian semi-parametric approach to estimate the parameter *d*. This estimate is consistent, more efficient and asymptotically normal in the range of $d \in (0, 0.5)$. It is assumed that the spectral density of the time series, denoted by $f(.)$, behave as

$$f(\xi) \sim G\xi^{1-2H} \quad as\ \xi \rightarrow 0^{+} \tag{4}$$

where, $G \in (0,\infty)$, ξ is the angular frequency and $H \in (0,1)$. The self similarity parameter *H* relates to the long-memory parameter *d* by $H = d + ½$. The estimate for *H*, denoted by $\hat{H}$, is obtained through minimization of the Equation (5) with respect to *H*:

$$R(H) = \ln \hat{G}(H) - (2H-1)\frac{1}{v}\sum_{\lambda=1}^{v} ln\xi_{\lambda} \tag{5}$$

where, $\xi_{\lambda} = \frac{2\pi\lambda}{T}$ denotes the Fourier frequencies of the sample, $v = g(T) \ll T$ is the number of Fourier frequencies included (that is number of low frequency ordinates) and $\hat{G}(H) = \frac{1}{v}\sum_{\lambda=1}^{v}\xi_{\lambda}^{2H-1}\, I(\xi_{\lambda})$. Here, *T* is the number of observations in the study. The discrete averaging is carried out over the neighborhood of zero frequency and, in asymptotic theory, *v* is assumed to tend to infinity much more slowly than does *T*. Gaussianity is nowhere assumed in the asymptotic theory. The Gaussian semi-parametric estimator is $v^{\frac{1}{2}}$ consistent and the variance of the limiting distribution is free of nuisance parameters and equals $\frac{1}{4v}$. The Robinson's method is not restricted to using a small fraction of the ordinates of the empirical periodogram of the series. The number of low frequency ordinates ($g(T)$) is defined as $g(T) = T^{0<\tau<1}$, where τ is the power. Number of studies has shown that there exists a great deal of subjectivity in choosing the correct number of low frequency ordinates in the analysis. Past studies (for example, Diebold and Rudebusch, 1989; Cheung and Lai, 1993; Barkoulas and Baum, 1997; 1998; Wilson and Okunev, 1999) pointed out that, if $g(T)$ is too large then the estimate d will be contaminated due to the medium and high frequency components of the spectrum and if too few ordinates are included in the estimation process then it will lead to imprecise estimates of d. In estimating the fractional component (d), a choice has to be made on the number of low frequency ordinates used in the Gaussian Semi-parametric approach. In this study, we report d estimates for $T^{0.5\le\tau\le0.8}$.

RESULTS AND DISCUSSION

The preliminary analyses of the weekly spot prices of the three indices strongly suggest the series are integrated of order one. That is they are $I(1)$ process. The natural logarithm of the series was considered in this research, since the transformation stabilized the variance.

Analysis of Bi-variate Cointegration Models

Considering two indices at a time, cointegration models were generated by using the OLS regression technique. Three cointegration models were produced based on the following variable pairs;

1. US WTI vs. Europe BRENT
2. Europe BRENT vs. OPEC
3. OPEC vs. US WTI

Then the residual series was obtained for each of the cointegration model and the stationarity of the residual series was tested for fractional process by estimating the fractional differencing parameter *(d)* by using the Robinson's test. The summary of the test results using the Robinson's test is presented in Table 1.

Table 1: Estimates of the fractional differencing parameter (*d*) from the Robinson's test for the residual series of the three cointegration models.

Cointegration model	Factors	Power (Ordinates[$g(T)$])			
		0.5(25)	0.6(49)	0.7(91)	0.8(175)
US WTI vs. Europe BRENT	Estimate (*d*)	0.141	0.289	0.408	0.487
	Test statistic(T)	0.9103	3.2302	7.0547	10.5808
	P>|T|	0.371	0.002***	0.000***	0.000***
Europe BRENT vs. OPEC	Estimate (*d*)	0.332	0.238	0.275	0.379
	Test statistic(T)	2.8383	3.0486	4.3661	7.3807
	P>|T|	0.009***	0.004***	0.000***	0.000***
OPEC vs. US WTI	Estimate (*d*)	0.303	0.451	0.452	0.436
	Test statistic(T)	1.8011	4.3932	6.0286	8.6421
	P>|T|	0.083*	0.000***	0.000***	0.000***

*and***indicate statistical significance at 10% and 1% level of significance respectively.

Table 1 indicates the null hypothesis of $d=0$ is rejected against the fractional order alternatives at most of the times and the estimated values for the d is in the range of 0 to 0.5 ($0 < d < 0.5$) in all the situations. This provides strong evidence to suggest that the residuals of all the cointegration models do have the characteristic of long term persistence. In other words, each of these oil indices is having long term co-movement with one another. Hence, fractional cointegration phenomena exist in these models. Furthermore, the residual series are stationary and they exhibit long range positive dependence.

Thus, in bi-variate terms there exists a long term co-movement among the oil indices. Additionally, the model of the Europe BRENT versus OPEC is significant at all the times by the Robinson's test. This implies that these two markets are highly fractionally cointegrated and thus, they are highly co-dependent. Moreover, the autocorrelation structures of the residual series generated by the three cointegrating regressions indicate long term persistence in the autocorrelation structure (slowly decaying with approximate hyperbolical manner). Hence, it complies with the test results obtained from the fractional value estimation.

Analysis of Cointegration Models Based on All Three Indices

The three indices were considered separately as the dependent variable and conduct three distinct linear regressions in order to formulate the cointegration equations. The three cointegration models were formulated by considering the following variable association;

1. US WTI vs. Europe BRENT and OPEC
2. Europe BRENT vs. US WTI and OPEC
3. OPEC vs. US WTI and Europe BRENT

Thereafter, residual series corresponding to each model were obtained. Finally the stationarity of the residual series were tested using the Robinson's test as done in the bi-variate cointegration model testing procedure. The summary of the test results using the Robinson's test is shown in Table 2.

Table 2 reports strong evidence to support the fractional cointegration processes in the models. Where, the d parameter estimates are all less than one. In fact d is in the range of 0 to 0.5 ($0 < d < 0.5$) as we have seen in the bi-variate models. Furthermore, the null hypothesis of $d = 0$ is rejected in favor of the fractional alternative at most of the times.

Therefore, it can be concluded that there exists long term persistence even among the three oil indices as a whole. However, by looking at the significance of the d parameter of the three models, the cointegration of the OPEC versus the US WTI and Europe BRENT seems to be more persistence than the other two models. Since, the null hypothesis of $d = 0$ is strongly rejected at all the levels of power. Furthermore, the autocorrelations of the residual series for the cointegration models exhibit long term persistent from their approximate hyperbolical decaying.

Table 2: Estimates of the fractional differencing parameter (*d*) from the Robinson's test for the residual series of the three cointegration models.

Cointegration model	Factors	Power (Ordinates[$g(T)$])			
		0.5(25)	0.6(49)	0.7(91)	0.8(175)
US WTI vs. Europe BRENT & OPEC	Estimate (*d*)	0.141	0.286	0.405	0.486
	Test statistic(T)	0.9171	3.219	7.0143	10.5244
	P>|T|	0.368	0.002***	0.000***	0.000***
Europe BRENT vs. US WTI & OPEC	Estimate (*d*)	0.114	0.177	0.254	0.337
	Test statistic (T)	0.7233	1.5204	3.168	6.4414
	P>|T|	0.476	0.135	0.002***	0.000***
OPEC vs. US WTI & Europe BRENT	Estimate (*d*)	0.299	0.218	0.264	0.372
	Test statistic (T)	2.4956	2.781	4.1742	7.2627
	P>|T|	0.019**	0.008***	0.000***	0.000***

and*indicate statistical significance at 5 % and 1% level of significance respectively.

CONCLUSIONS

There exists a strong fractional cointegration structure among the oil price indices during the study period in terms of bivariate models as well as among all the three indices. The presence of fractional cointegration between these oil indices would suggests that diversification, in terms of investing in these markets may not produce the risk reduction benefits expected. However, it was identified that there is a tendency in OPEC to follow the US WTI and Europe BRENT even though in long run they are in an equilibrium state.

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