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Article

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A Nonlinear Empirical Analysis of Oil Price Co-movements

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ABSTRACT

Nonlinear co-movements are analyzed for the daily returns calculated for Brent and West Texas Intermediate (WTI) crude oil prices. The sample period includes data for the pre-2008 price increases and the post-2014 price declines. Empirical results obtained indicate that it is important to allow for nonlinear and asymmetric patterns in the data. After doing so, unidirectional causality from Brent to WTI is documented with price declines exerting more reliable effects than price gains. That is in contrast to what has been documented for other sample periods that do not allow for potential nonlinear and asymmetric linkages.

Keywords: Nonlinear Tests, Co-movement, Crude Oil Prices, Granger Causality
JEL Classifications: C32, G15, Q43

1. INTRODUCTION

The crude oil market is large and prominent. Changing conditions in the oil market often affect prices in other commodity markets (Lee et al., 2012; Nazlioglu and Soytas, 2011; Saghaian, 2010; Sari et al., 2010). Beyond that, oil market developments frequently affect other financial markets (Imarhiagbe, 2010; Liu et al., 2013; Reboredo et al., 2014). Finally, oil price shocks can even precipitate fairly large macroeconomic adjustments in many countries (Clements and Krolzig, 2002; Filis et al., 2011; Guesmi and Fattoum, 2014; Mehrara, 2008; Wang et al., 2013; Donayre and Wilmot, 2016; Gbatu et al., 2017).

This study analyzes nonlinear co-movements between the prices and returns for two widely quoted grades of crude oil: Brent and West Texas Intermediate (WTI). Substantial co-movement appears to exist among the two price series. Exact quantification of that co-movement during the recent price decline has not, however, been examined. Preliminary evidence indicates that the stable relationship between Brent and WTI prices that existed prior to 2007 has been altered (Chen et al., 2015; Fattouh, 2010). More specifically, the price spread between WTI and Brent appears to have become less stable subsequent to 2010. Such a development raises questions about the usefulness of WTI as an international benchmark price.

Material in this effort attempts to partially fill those gaps in the energy economics literature by analyzing the co-movements of these widely utilized crude oil price measures. The focus of this effort is potential nonlinear causal associations between the prices. Examination of potential nonlinearities and asymmetries between the returns for these two oil products is also completed.

2. DATA

Spot prices for WTI and Brent petroleum are used for this study. WTI is known as light, sweet crude oil because it is a grade of oil that has both a low density (light) and low sulfur (sweet) content. By volume, it is the most highly traded commodity on the New York Mercantile exchange. WTI is processed at refineries located along the Gulf Coast and in the Midwestern regions of the United States and is well-suited for gasoline production. Brent is also a light sweet crude oil that is extracted from the bed of the

North Sea. It is used as a benchmark for Atlantic basin crude oils and serves as a reference price for approximately 65 percent of all crude oil supplied worldwide. Brent oil is particularly well-suited for refinement into diesel fuel.

The period analyzed is from 20 May 1987 to 2 November 2015, providing a total of 7424 daily observations. This sample period is sufficiently long enough to study the co-movement of oil prices during several interesting periods. The latter include the recent downturn for the industry when prices fell from a maximum of $145.31 USD per barrel to a minimum of $10.82 USD for WTI. The corresponding figures for Brent are a maximum price of $144.07 USD and a minimum price of $9.22 USD per barrel.

As shown in Figure 1, substantial co-movement appears to exist among the two price series. Quantification of that co-movement during the recent price decline has not, however, been very extensively examined. Preliminary evidence indicates that the stable relationship that existed prior to 2007 has been altered (Chen et al., 2015; Fattouh, 2010). More specifically, the price spread between Brent and WTI appears to become less stable for the period subsequent to 2010. During that period, the Brent-WTI spread occasionally exceeded $20 per barrel (Ajmi et al., 2014). Superficially, that unexpected development may cast some doubt on the usefulness of WTI as an international benchmark price, but it does not examine if more complicated relationships exist between the two price series.

It is worth noting that regional price discrepancies can occur among different crude oils. For widely traded crudes such as Brent and WTI, this should not pose a problem for the type of analysis completed in this study. In general, daily crude petroleum prices tend to be much more correlated than equity markets where dispersions can be fairly large (Dai et al., 2016). For this effort, what is of more interest is the underlying nature of the co-movements between the daily returns for these two oil prices.

Descriptive statistics for the prices of Brent and WTI are reported in Table 1 (prices column). The statistics are generally consistent with stylized facts calculated for other financial time series (Cont, 2001) and for oil markets (Choi and Hammoudeh, 2009). The prices for Brent and WTI have similar means, but somewhat different medians and modes. The standard deviation for the Brent price is larger than that for WTI, potentially because the former is used as a reference price for internationally produced oil from a larger number of countries. Both prices are positive-skewed and Platykurtic. Given that, it is not surprising that the Jarque-Bera statistics in Table 1 indicate that neither price series follows a Gaussian distribution pattern. Finally, the sample ranges for both prices are very large, $134.85 for Brent and $134.49 for WTI. That reflects the volatile nature.

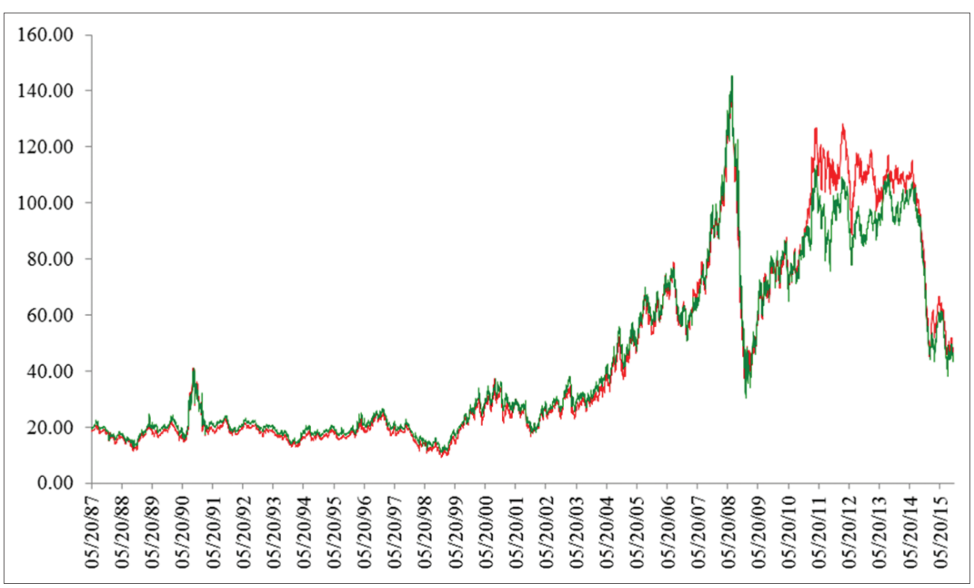
Table 2 (returns column) summarizes descriptive statistics for the nominal daily returns. The mean rates of return are positive for both prices, but the median and mode values for both variables are equal to zero. The daily returns are negative skewed and highly leptokurtic. The volatility of the daily returns is underscored by the large ranges associated with both crudes. Neither set of daily compound returns follows a normal distribution.

Table 1: Nominal price and return descriptive statistics

Statistic	Brent		WTI	
	Prices	Returns	Prices	Returns
Observations	7424	7423	7424	7423
Mean	$44.96	0.01	$44.20	0.01
Median	$26.81	0	$28.36	0
Mode	$17.90	0	$20.28	0
Standard Deviation	$34.46	2.25	$30.86	2.41
Skewness	0.97	−1.02	0.9	−0.79
Kurtosis	2.54	27.05	2.48	19.14
Maximum	$144.07	15.23	$145.31	18.83
Minimum	$9.22	−44.2	$10.82	−40.69
Jarque-Bera	1,240.57	180,191.50	1,092.59	81,396.20

Jarque-Bera statistics reject the null hypothesis of data normality for both series. Sample data from May 20th 1987 to November 2nd 2015, WTI: West Texas Intermediate

Figure 1: Nominal U.S. dollars per barrel. West Texas intermediate prices in green, Brent prices in red. Sample data from May 20th 1987 to November 2nd 2015



3. UNIT ROOT TESTS

Unit root tests are used to examine whether the oil price series are I(1). There are several different methods available for a unit root testing. Two are employed in this chapter. The first is the well-known augmented Dickey-Fuller (ADF) unit root test evaluates the null hypothesis that a time series is I(1), against an alternative that it is I(0). The ADF test is carried out under the assumption that the data are generated by an autoregressive – moving average process (Phillips and Perron, 1988).

The second unit root test procedure utilized is one that does not require knowledge of a specific density function or functional form. It utilizes non-normality information contained in the higher order moments of the residuals from a regression equation. Known as a residual augmented least squares (RALS) test, usage is spreading quickly because it is applicable to data that are not generated by Gaussian density functions (Im et al., 2014). Results from both procedures are shown in Table 2.

The ADF and RALS tests are conducted with trend and intercept, as well as with drift for each series in the sample. The results in Table 2 indicate that the Brent and WTI prices can be characterized as I(1) processes. The returns for each price variable are stationary. Tests for cointegration and co-movement are completed in the next section.

4. COINTEGRATION

As Engle and Granger (1987) shows, in a bivariate cointegrated system, Granger causality must exist in an least one direction between the time series in such a system. To examine whether that is the case in this sample, the Johansen (1991) test of the null hypothesis of no cointegrating factors is conducted. The results in Table 3 indicate that the null hypothesis of no cointegrating factor cannot be rejected for r <1, providing evidence that the two oil price series are cointegrated. The cointegrating vector is β = (1, −1.125).

Table 2: Unit Root Test Results

Test	Brent		WTI	
	Prices	Returns	Prices	Returns
With trend and intercept				
ADF	−1.81	−83.19*	−2.22	−88.44*
RALS	−1.5	−86.45*	0	−91.68*
With drift				
ADF	−1.4	−83.20*	−1.59	−88.44*
RALS	−0.98	−86.45*	1.8	−91.68*

*Indicates that the null hypothesis of unit root presence is rejected at the 1% level

Table 3: Cointegration rank: Maximum eigenvalue statistics

Hypothesis	Statistic	10%	5%	1%
r<1	2.1	6.5	8.18	11.65
r=0	45.32	12.91	14.9	19.19

The null hypothesis of non-rejection indicates the number of cointegrating vectors

5. LINEAR GRANGER CAUSALITY

Causal links between the two crude oil prices are analyzed next (Granger, 1969). The null hypotheses for the standard Granger causality F-test assume data normality. Given the computed Jarque-Bera Chi-squared statistics in Table 1, that is clearly a very strong assumption and will be given more attention below (Arratia, 2014). Table 4 reports the standard Granger causality results using an F-test approach. Bi-directional causality is found to exist between the daily oil price return series.

6. NONPARAMETRIC GRANGER CAUSALITY

The deployment of nonparametric versions of the Granger non-causality hypothesis test instead of linear, and nonlinear, Granger causality is sometimes useful (Bell et al., 1996; Hiemstra and Jones, 1994; Su and White, 2008). The linear Granger causality test might fail to uncover nonlinear causal relationships that can be precipitated by sudden changes in oil prices related to supply, demand, unexpected geopolitical events, and other shocks. Given that, the Diks and Panchenko (2006) (hereafter DP) nonlinear Granger causality test is also employed. Once again, the results in Table 5 indicate that bi-directional feedback exists between the daily oil price return series.

7. NONLINEAR AND ASYMMETRIC GRANGER CAUSALITY

Using both linear and nonparametric Granger causality tests, bidirectional causality between Δln(WTI) and Δln(Brent) has been found to exist. It is also useful, however, to examine whether there is causality in the presence of chaotic dynamics, as might be the case for global oil prices. It is of further interest to confirm whether certain asymmetries, such as conditioning

Table 4: Granger causality computed f-statistics for returns

Lags	Brent ↛ WTI	ETI ↛ Brent
1	28.58*	117.90*
2	18.30*	62.37*
3	13.38*	41.92*
4	10.13*	34.44*
5	9.07*	27.74*

*Indicates that the null hypothesis of no causal relationship H_0: $X_t \nrightarrow Y_t$ is rejected at the 1% level

Table 5: Nonparametric granger causality computed $T_n(\epsilon)$ statistics for returns

Lags	Brent ↛ WTI	WTI ↛ Brent
1	6.94*	7.69*
2	6.67*	6.53*
3	4.48*	5.11*
4	4.07*	3.91*
5	3.23*	3.95*

*Indicates that the null hypothesis of no causal relationship H_0: $X_t \nrightarrow Y_t$ is rejected at the 1% level. The value used for ϵ is 0.63

to either positive or negative returns, also generate causal links between the series.

The Kyrtsou and Labys (2006) symmetric nonlinear causality test is useful in this regard because it can capture fairly complicated dependent dynamics between the series. Such a test is similar to the classical Granger causality test, with the difference that it attempts to detect if past values of a variable X_t, have a significant nonlinear effect of the type $X_{t-\tau_2}/(1+X_{t-\tau_2}^{c_2})$ on the current value of another variable Y_t (Ajmi et al., 2014; Hristu-Varsakelis and Kyrtsou, 2010). The aforementioned nonlinear effect is related to the discrete version of the Mackey-Glass equation (Mackey and Glass, 1977), which has been used in this and other tests because of its ability to uncover complicated dynamics in economic time series (Kyrtsou and Terraza, 2003). Along these lines, positive (Asymmetric$^{(P)}$) and negative (Asymmetric$^{(N)}$) shock tests are also completed (Hristu-Varsakelis and Kyrtsou, 2008).

Table 6 reports the symmetric, asymmetric$^{(P)}$, and asymmetric$^{(N)}$ results using an F-test approach. A unidirectional nonlinear Granger causal relationship from Δln(Brent) to Δln(WTI) is found to exist. However, no reverse direction causality is documented from Δln(WTI) to Δln(Brent). These results run counter to what is reported in Tables 5 and 6. As such, an important point is highlighted. Namely, once potential nonlinearities and asymmetries are taken into account, there is no causality from Δln(WTI) to Δln(Brent). Furthermore, when Δln(Brent) is greater than zero, it exercises no statistically reliable effect on from Δln(WTI) during the 20 May 1987 to 2 November 2015 sample period under consideration.

The results in Table 6 agree with at least some evidence that the empirical linkages between Brent and WTI have been altered from 2010 forward (Chen et al., 2015). Those results also, however, run counter to nonlinear Brent and WTI bi-directional causality results reported for daily data from January 2013 through October 2015 (Coronado et al., 2016) while several factors make the results in Table 6 seem plausible, it also appears that causal links between crude petroleum prices are relatively sensitive to both methodology and, perhaps more importantly, sample period.

Acknowledging the latter possibility, there are still interesting implications associated with the results shown in Table 6. Causal linkages between Brent and WTI daily returns appear fairly tenuous. For the sample period in question, those links, such as they are, only run from Brent to WTI. Even more intriguing are the asymmetric$^{(P)}$ results in Table 6 that indicate positive changes in either oil price do not translate to statistically reliable effects on the other series. The oil market seemingly is more vigilant with respect to downside risks than to potential upswings.

Table 6: Nonlinear and asymmetric granger causality F-statistics

Case	Brent ↛ WTI	WTI ↛ Brent
Symmetric	11.98*	0.35
Asymmetric$^{(P)}$	2.51	0.05
Asymmetric$^{(N)}$	22.21*	3.65

*Indicates that the null hypothesis of no causal relationship H_0: $X_t \nrightarrow Y_t$ is rejected at the 5% level. Asymmetric$^{(P)}$ and asymmetric$^{(N)}$ are computed asymmetric test statistics for positive and negative changes in the causal variable X_t, respectively. The values of $\tau_1 = \tau_2 = 1$, $c_1 = c_2 = {}_2$ used are based on BIC criterion

Although the results in Table 6 are surprising, they are not entirely surprising. As noted by Chen et al. (2015), the relationship between Brent and WTI prices changed after 2007 and that period includes the sample used for this study. More specifically, the Brent - WTI price spread became much less stable subsequent to 2010. At least during part of that period, it appears that two series are directionally linked whenever the Brent price declines. Neither series responds, however, to increases in the other price during the period in question. The absence of causal links between these crude oil prices is in contrast to what has been documented using data for 2014 and 2015 (Coronado et al., 2016).

In that context, it appears that international oil markets are subject to greater econometric instability and temporal heterogeneity than might otherwise be expected on the basis of the historical record prior to 2010. Structural breaks are becoming more common and nonlinearities appear to a more common feature of oil market returns than was previously suspected (Block et al., 2015). Under these conditions, failure to take into account nonlinear causal links and asymmetric reaction patterns can lead to mistaken inferences regarding the behavior of the daily returns associated with Brent and WTI prices.

8. CONCLUSION

Nonlinear co-movements between the prices and returns for Brent and WTI crude oil are examined in this study. The sample period is from 20 May 1987 to 2 November 2015 and includes the price decline of 2014. Substantial co-movement appears to exist among the two price series, but results obtained differ from many that have been published in recent years for other time periods.

In particular, tests that do not allow for potential nonlinearities or asymmetries indicate that statistically significant bi-directional causality exists between these two widely quoted oil prices. After allowing for nonlinearities and asymmetries, however, different results are obtained. More specifically, there appears, for this sample period using daily data, to be asymmetric unidirectional causality that runs from Brent to WTI when price declines occur for the former.

These results do not rule out the possibility of other types of causal linkages between these two important grades of petroleum for other sample periods. Smoother frequencies such as weekly, monthly, quarterly, or annual, may also have different causality patterns than those discussed above. The outcomes reported in this study do, however, underscore the importance of allowing for nonlinearities and asymmetries in how the data behave over time.

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