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The Price Correlation between Crude Oil Spot and Futures – Evidence from Rank Test

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Abstract:

This paper examines between the petroleum futures and spot prices have non-linear equilibrium relationships towards equilibrium using rank tests by Breitung (2001). We then estimate the asymmetric Bivariate TECM GJR-GARCH model to capture the short-run and long-run dynamic adjustments with the asymmetric price and volatility transmissions between the petroleum spot and futures markets. We find the petroleum futures prices are cointegrated and nonlinear with spot prices in the long-run. This effectively confirms the expectations hypothesis. In the mean equations, we find evidence that the spot price adjusts strongly to a positive basis in the short-run, and they will revert to the long-run equilibrium level. In the variance equations, we find that when bad news happens in the petroleum spot and futures markets, volatility will increase in its own market. Besides, asymmetric effects are also found in both the petroleum spot and futures market in our conditional variance models.

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Keywords: Rank Test; Asymmetric Threshold Error-Correction Model; Bivariate GJR-GARCH Model; Asymmetric Volatility

1. Introduction

The crude oil futures markets play an important role in economic development and industrialization, the arbitrageurs, speculators, producers, and policymakers refer to the futures market for predicting future spot prices and minimizing their risk. A number of studies have appeared that stationarity of petroleum spot-futures relationship suggests any series adjusts asymmetrically that short-run deviations from the long-run equilibrium will be countervalied by a mean-reverting behavior. This asymmetric relationship between the spot and futures markets can be attributed to lower transaction costs and less restrictive short selling in the futures market. Coppola (2008) exploits the cost of carry model is employed to justify the

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existence of a long-run relationship between spot and futures prices, short-run deviations from this equilibrium will be counterevalved by a certain degree of mean reversion in the spot-futures basis. Dumas (1992) and Sarantis (1999) analyze the dynamic process of the real exchange rate within a general equilibrium model, and find the transaction costs if existence, then show that the model produces endogenously a non-linear real exchange rate process. The error-correction model facilitates nonlinear adjustments characterize mean reversion while the real exchange rate probability of a move away from the parity value and have opportunity to arbitrage. The dynamic adjustment of the petroleum futures basis is not always capable of providing any precise specification of the functional form, such that non-parametric tools for use in estimation and inference are clearly desirable. And most relevant studies now find that the petroleum of the spot and futures market is both non-linear and asymmetric. Fattouh (2010) uses the evidence of non-linearity in the adjustment process and asymmetric suggests the presences of transaction costs and/or the absence of riskless arbitrage which may cause oil markets to wander off from each other.

The present study use the non-linear co-integrational evidence on the petroleum spot-futures markets based on the non-parametric rank tests developed by Breitung (2001), which demonstrate power in both linear and non-linear frameworks, and it is also applicable to whatever the data generating process of the variables under examination. One particular advantage of these rank tests is that there is no requirement to be explicit with regard to the exact functional form of the non-linear cointegrating relationship. Furthermore, we adopt the Bivariate Glosten, Jagannathan and Runkle (1993) GARCH to investigate the volatility transmission and the asymmetric relationships between the petroleum spot-futures market.

There are, therefore, several important issues that are of particular interest to this study. Firstly, our primary objective in this study is to examine between the petroleum futures and spot prices have non-linear equilibrium relationships towards equilibrium using rank tests proposed by Breitung (2001). Secondly, we use the asymmetric threshold error-correction (TECM) to capture the short-run and long-run dynamic adjustments with the asymmetric price transmissions between the petroleum spot and futures markets. Finally, we adopt the Bivariate GJR-GARCH model to investigate the volatility transmission and the asymmetric relationships between the petroleum spot-futures market, and our results should have the implications for investing strategies on trading petroleum futures and spot contracts. The methodology adopted is described in Section 3. Then Section 4 contains the data source and empirical analysis. Finally, the conclusions drawn from this study are presented in Section 5.

2. Expectations Hypothesis

The relationship between spot and futures prices is the key to extract valuable information from the futures market. The expectations hypothesis of storage (Karatzas and Shreve 1998) explain the futures price is an unbiased estimate of the expected future spot price under risk neutrality, and thus the standard derivatives pricing theory is let the basis, \( B_t = S_t - F_t \), and can be written as

\[
B_t = -\left(1 - \frac{T}{t}\right) \{ E_{t+1}(S_t) - S_t \}
\]

3. Methodology

3.1. Cointegration and Non-Linearity Rank Test
Breitung (2001) proposes the rank tests for testing cointegration relationship between two time series \( y_t \) and \( x_t \). When the test statistic takes on a value smaller than the appropriate critical values, this provides evidence against the null hypothesis of no cointegration.

Breitung (2001) let \( x_t \) and \( y_t \) be two mutually and serially uncorrelated random walks, then developed the following test statistics:

\[
\psi_1^* = \sup_{t < T} \left| d_t \right| / T \sigma_{ud}, \quad \text{and} \quad \psi_2^* = \sum_{t=1}^{T} d_t^2 / T \sigma_{ud}^2
\]

Whenever the rank test for cointegration indicates a stable long-run relationship, it is interesting to determine whether the cointegrational relationship is linear or non-linear. In order to convenient representation of such linear or non-linear hypothesis, Breitung (2001) assumed that \( x_t \) is exogenous and \( e_t \) is white noise with \( e_t \sim N(0, \sigma^2) \), a score test statistic is obtained as the \( T \cdot R^2 \) statistic. Under the null hypothesis, the \( R^2 \) has an asymptotic \( \chi^2 \) distribution with one degree of freedom. Surprisingly, the Monte Carlo simulations carried out by Breitung (2001) show that, the rank test may even be more powerful than the parametric counterparts.

3.2. Bivariate TECM with GJR-GARCH Model Test

Following the positive finding of a non-linear equilibrium relationship, we use the nonlinear threshold model with the Bivariate TECM GJR-HARCH (1,1) process to capture the short-run and long-run dynamic adjustment process with regard to the petroleum spot-futures markets. GJR-GARCH equation will be:

\[
\Delta S_t = \alpha_{S,0} + \sum_{i=1}^{k} a_{S,i} \Delta S_{t-i} + \sum_{j=1}^{k} a_{F,j} \Delta F_{t-j} + \theta_{1S} Z_{-} \text{plus} + \theta_{2S} Z_{-} \text{min} \text{us} + e_{S,t}
\]

\[
\Delta F_t = b_{F,0} + \sum_{i=1}^{k} b_{S,i} \Delta S_{t-i} + \sum_{j=1}^{k} b_{F,j} \Delta F_{t-j} + \theta_{1F} Z_{-} \text{plus} + \theta_{2F} Z_{-} \text{min} \text{us} + e_{F,t}
\]

The second moment equations estimate the two conditional variance and covariance. Equations can be expressed as:

\[
h_{S,t} = \omega_{s,0} + \beta_{s} h_{S,t-1} + \gamma_{S} e_{S,t-1}^2 + \delta_{S} e_{S,t-1}^2 I_{S,t-1} + \eta_{S} e_{F,t-1}^2 I_{S,t-1} \quad (1)
\]

\[
h_{F,t} = \omega_{F,0} + \beta_{F} h_{F,t-1} + \gamma_{F} e_{F,t-1}^2 + \delta_{F} e_{F,t-1}^2 I_{F,t-1} + \eta_{F} e_{S,t-1}^2 I_{F,t-1} \quad (2)
\]

\[
h_{S,F,t} = \omega_{S,F,0} + \beta_{S,F} h_{S,F,t-1} + \gamma_{S,F} e_{S,t-1}^2 e_{F,t-1} + \delta_{S,F} e_{S,t-1}^2 e_{F,t-1} + \eta_{S,F} e_{S,t-1}^2 I_{S,F,t-1} \quad (3)
\]

4. Data and Empirical Results

4.1. Data

The data used in this study comprises of petroleum spot and futures prices. The daily data on the closing spot price \( (S_t) \) and daily futures price \( (F_t) \) for West Texas Intermediate (WTI) petroleum contracts at day \( t \) used to calculate the futures basis are sourced mainly from the databank of New York
Mercantile Exchange of New York from January 1, 2004 through September 30, 2009, and thus 1,500 observations are examined.

4.2. Cointegration and Non-linear Tests

The results of the rank and non-linear tests are estimated in this study are summarized in Table 1. We observe cointegrating relationships between the petroleum spot and futures markets. It is clearly evident from Table 1, which summarized the linearity test results that the cointegration relationship established earlier by the rank tests for cointegration can be said to be nonlinear in nature.

Table 1 Result of the cointegration and non-linearity rank tests

<table>
<thead>
<tr>
<th>Bivariate Rank Test</th>
<th>Rank Sum Linearity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi_1^*$</td>
<td>$\psi_2^*$</td>
</tr>
<tr>
<td>0.2694 ***</td>
<td>0.00057 ***</td>
</tr>
</tbody>
</table>

Notes:
a The rank test is adjusted for autocorrelation. The null hypothesis of the rank test is that no cointegration exists between the petroleum futures and spot prices; the alternative hypothesis is that cointegration does exist between the two prices. The null hypothesis is rejected when the critical value exceeds the test statistic.
b The null hypothesis of the rank sum linearity test is that a linear relationship exists with no cointegration between the petroleum futures and spot prices; the alternative hypothesis is that a linear relationship does not exist and cointegration does exist between the two prices. The null hypothesis is rejected when the computed $T \cdot R^2$ value exceeds the critical value.
c *** indicates significance at the 0.01 level; ** indicates significance at the 0.05 level; and * indicates significance at the 0.1 level.

4.3. Bivariate TECM – GJR GARCH

The evidence from our rank test and score test support the long-term equilibrium relationships between the petroleum spot and futures markets, and that an asymmetric threshold cointegration relationship does exist.

The Bivariate TECM – GJR GARCH model of mean equation can be expressed as follows:

$$\Delta S_t = 0.0009 + 0.2642\Delta S_{t-1} + 0.2393\Delta S_{t-2} + 0.2258\Delta S_{t-3} + 0.2897\Delta S_{t-4} + 0.2120\Delta S_{t-5} - 0.3126\Delta F_{t-1} - 0.3967\Delta F_{t-2} - 0.2166\Delta F_{t-3} - 0.2135\Delta F_{t-4} - 0.1828\Delta F_{t-5} - 0.6410Z_{-\text{plus}} + 0.068IZ_{-\text{min}} \min us + \varepsilon_{S,t}$$

$$\Delta F_t = 0.0003 + 0.2369\Delta S_{t-1} + 0.1843\Delta S_{t-2} + 0.2363\Delta S_{t-3} + 0.2861\Delta S_{t-4} + 0.1970\Delta S_{t-5} - 0.2802\Delta F_{t-1} - 0.3394\Delta F_{t-2} - 0.2292\Delta F_{t-3} - 0.2287\Delta F_{t-4} - 0.1729\Delta F_{t-5} - 0.2221Z_{-\text{plus}} - 0.0188Z_{-\text{min}} \min us + \varepsilon_{F,t}$$
The point estimates of the error correction terms signal the petroleum spot price adjusts strongly to a positive basis from a long-run equilibrium and moderately to a negative basis, while the futures price adjusts to a positive basis, but not to a negative basis. This evidence seems to suggest that, a positive basis for the change in the basis above the threshold persists longer than a negative basis for the change in the basis below the threshold.

The Bivariate TECM – GJR GARCH model of variance equation can be expressed as follows:

\[ h_{S,t} = 0.00039 + 0.1377h_{S,t-1} + 0.3299\varepsilon_{S,t-1}^2 - 0.1831\varepsilon_{S,t-1}^2I_{S,t-1} + 0.1943\varepsilon_{F,t-1}^2I_{S,t-1} \]
\[ h_{F,t} = 0.0004 + 0.1254h_{F,t-1} + 0.3321\varepsilon_{F,t-1}^2 - 0.0749\varepsilon_{F,t-1}^2I_{F,t-1} + 0.088\varepsilon_{F,t-1}^2I_{F,t-1} \]
\[ h_{S-F,t} = 0.00041 + 0.1152h_{S-F,t-1} + 0.3247\varepsilon_{S,t-1}\varepsilon_{F,t-1} + 0.0229\varepsilon_{S,t-1}\varepsilon_{F,t-1}I_{S,F,t-1} \]

The Bivariate TECM GJR-GARCH models are correctly specified. The results pointed out significant asymmetric volatility effects between spot and futures markets; the empirical evidence suggests that there is information flow (transmission) between the two markets.

5. Conclusions

This paper tests cointegration for the petroleum futures basis series using rank test method. The null hypothesis of no cointegration for the basis is rejected at the 1% level, which is supportive of the expectations hypothesis. This implies that there is no arbitrage opportunity on futures contracts over a long period of time. Furthermore, we investigate that long-run nonlinear equilibrium relationship that exists within the petroleum spot and futures markets using non-parametric rank test proposed by Breitung (2001). The rank tests cointegration method provides strong evidence of a long-run equilibrium relationship characterized by nonlinear adjustment. Then, we used the TECM, finding the petroleum spot and futures markets will revert to the long-run equilibrium level when in a disequilibrium term. Apparently, the point estimates of the error correction terms signal the spot price adjusts strongly to a positive basis from a long-run equilibrium. Besides, in our conditional variance equations we find asymmetric effects using Bivariate GJR-GARCH model, knowing when “bad news” happens in the petroleum spot and futures markets, volatility of its own market will increase. The empirical result also reveals that the petroleum spot and futures markets have interactive effect; this evidence suggests that there is information flow (transmission) between the two markets. Accordingly, the speculators, hedgers, and financial managers can obtain more insights into the management of their short-run investing and hedging strategies on petroleum futures contracts.

References