An Analysis About Market Efficiency in International Petroleum Markets: Evidence from Three Oil Commodities

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Abstract. A modified model for testing market efficiency is presented, with introducing convenience yield and using lagged spot prices to adjust risk premium. Subsequently, an examination about market efficiency in international petroleum markets is given using the modified model for three widely traded oil commodities: WTI crude oil, unleaded gasoline, and heating oil. The main findings are that there have significant differences about market efficiency in different oil futures markets, and a nonlinear relationship among spot price, futures price, risk premium, and convenience yield is found in the crude oil market but not in refined oil markets. The nonlinear relationship can be eliminated through dividing the observed period into several stages. Meanwhile, the crude oil futures market is more and more efficient.

Keywords: International petroleum markets, Market efficiency, Futures price spot price, Risk premium, Convenience yield, Cointegration analysis.

1 Introduction

Today, oil is the world's most heavily exchanged commodity, with frequently fluctuation of its prices. Correspondingly, the oil futures markets play a more and more important role in the international oil markets. So the behavior about market efficiency in oil futures markets is arresting.

Several studies have examined this market efficiency in oil markets with mixed results. Bopp and Sitzter [1] argue that futures prices are good predictors of spot prices in the heating oil market. Ma [2] examines the existence of a risk premium for crude oil, heating oil, and leaded gasoline futures with maturities of 1, 2, 3, and 6-months. The results provide little evidence for a risk premium and there does not appear to be a systematic bias in the observed futures prices, supporting the simple efficiency hypothesis. Serletis and Banack [3] provide evidence that spot prices for crude oil, heating oil, and unleaded gasoline are cointegrated with their respective futures prices, but they do not explicitly test the joint restrictions implied by the unbiased hypothesis.

Using monthly observations of 30-day crude oil futures, Crowder and Hamed [4] test the simple efficiency hypothesis and the arbitrage condition, and obtain the conclusion supporting the former one. Roger and Mougoue [5] present some empirical results that the market efficiency hypothesis is supported by the data after the presence of nonlinear dependence using BDS test statistic and GARCH model. Recently, Joseph, Higgins and Miller [6] point out that oil futures prices do not predict well, and not also provide any easy way to predict the price of oil is headed. They attribute this result to convenience yield of oil storage.

So far, we can derive an elementary impression from above discussion that the market efficiency of oil futures markets is increasingly suspect due to frequent fluctuation of oil along with market speculation. Hence, further empirical testing is required to resolve, or at least to shed some light on, this issue as applied to the oil market.

The objective of this paper is to provide an empirical analysis about market efficiency in oil futures markets based on a modified testing model.

2 Models and Data

The efficiency of the futures markets in commodities or currency exchange has been extensively tested using the model

$$S_t = \alpha_0 + \alpha_1 F_{t-1} + \varepsilon_t \quad (1)$$

where S_t is the natural logarithm of the spot price in period t and F_{t-1} is the analogously defined futures price in period $t-1$ with the maturity period t , ε_t is stochastic error. In eq. (1), if $\alpha_0 = 0$, $\alpha_1 = 1$ and ε_t is white noise, then the futures market is weak form efficiency (see [7]). Weak form efficiency is also called as simple efficiency.

Subsequently, Brenner and Kroner [8] derive the conditions for market efficiency under the no arbitrage rule. Their model is

$$S_t = \alpha_0 + \alpha_1 F_{t-1} + \alpha_2 R_t + \varepsilon_t \quad (2)$$

where S_t , F_{t-1} and ε_t are defined as in eq. (1), R_t is the continuously compounded rate of return on the risk-free bond. A necessary condition for futures market efficiency is that there is a cointegration relationship among variables S_t , F_{t-1} , R_t , and the error term is serially uncorrelated as well as $\alpha_1 = \alpha_2 = 1$.

However, eq. (2) ignores two points. One point is the convenience yield of commodities storage. The other is how to calculate the risk premium. For oil commodities, first, it has a use option: if your refinery really needs input today, you can send your own oil to it. On the other hand, oil is easy to store in the ground, thus, you have some opportunities to obtain higher benefit when oil price rises. In addition, convenience yield comes often from oil shortage in a short future time.

In general, convenience yield is unobserved and uncertain. Gibson and Schwartz [9] estimate the convenience yield in the oil commodity market, and demonstrate that the convenience yield has significant mean reversion tendencies and conclude that it is a stationary process. We utilize this result to modify eq. (2).

Let y_t be convenience yield of oil commodity in period t , then y_t may be denoted as

$$y_t = \mu + u_t, \quad h_t = h_0 + \sum_{i=1}^q \beta_i u_{t-i}^2 + \sum_{j=1}^p \theta_j h_{t-j} \quad (3)$$

where μ is the mean value of convenience yield and h_t is the conditional variance of the error u_t . Here, h_t is expressed as a generalized autoregressive conditional heteroscedasticity process, i.e. GARCH model. The investors perhaps hope to gain convenience yield from oil storage. Therefore, eq. (2) should comprise y_t , i.e.

$$S_t = \alpha_0 + \mu + \alpha_1 F_{t-1} + \alpha_2 R_t + u_t + \varepsilon_t. \quad (4)$$

Let $\alpha_0 + \mu = \mu_0$ and $u_t + \varepsilon_t = w_t$, then we obtain

$$S_t = \mu_0 + \alpha_1 F_{t-1} + \alpha_2 R_t + w_t, \quad h_t = h_0 + \sum_{i=1}^q \beta_i w_{t-i}^2 + \sum_{j=1}^p \theta_j h_{t-j}. \quad (5)$$

where h_t is the conditional variance of the error w_t .

The second problem involves the calculation of the risk premium. We know that the investors only need to provide a small part of margin (about 5-10% of contract value) for buying or selling futures contracts. Therefore, the risk premium mainly concerns spot commodities but not futures contracts. According to this point, we adjust R_t in eq. (2) as follows

$$R_t = S_{t-1} r_t. \quad (6)$$

where S_{t-1} is the spot price in period $t-1$ and r_t is continuous compounding rate. Combines eq. (5) with eq. (6), we can obtain

$$S_t = \mu_0 + \alpha_1 F_{t-1} + \alpha_2 S_{t-1} r_t + w_t, \quad h_t = h_0 + \sum_{i=1}^q \beta_i w_{t-i}^2 + \sum_{j=1}^p \theta_j h_{t-j}. \quad (7)$$

where all symbols in eq. (7) have the same definitions with eq. (5) and (6).

So far we argue the futures market is efficient if eq. (7) satisfies the conditions: (a) there is a cointegration relationship among variables S_t , F_{t-1} and $S_{t-1} r_t$; (b) $\alpha_1 = 1$ and $\alpha_2 = 1$; (c) w_t is serially uncorrelated and its mean value is zero.

The data used to test the efficiency of the oil futures markets are monthly observations from New York Mercantile Exchange (NYMEX), including three oil commodities: WTI crude oil, unleaded gasoline, and heating oil. The oil futures and spot prices series are available at <http://www.eia.doe.gov>. The observed period for WTI

is from Jan. 1986 to Dec. 2004, but for the latter two commodities is from Jun. 1986 to Dec. 2004. The futures price is defined as the closing price of a futures contract 30 days prior to the last day of trading on that contract. The future spot price is the cash price on the last trading day of the corresponding futures contract. The risk-free rate series is defined as the interest rate on the 3-month contract U.S. Treasury Bill that matures nearest to the last trading day of the relevant futures contract, and the data are available at <http://www.economagic.com/>. All variables are transformed into natural logarithm for eliminating in certain extent the heteroscedasticity of the error in eq. (7). The software we used is SAS 8.2.

3 Empirical Results

3.1 Stationarity Tests

The ADF unit root tests for the spot price, futures price and risk-free return of each oil product show that all these series are nonstationary. At the same time, all first differences are stationary, i.e., all these series are $I(1)$ (integration of order one).

3.2 Cointegration Analysis

3.2.1 A Linear Analysis

It is important to point out that the risk-free return $R_t = S_{t-1}r_t$ is quite little (less than 1 in general) in the real oil markets, so the natural logarithm of R_t is negative. Thus, it is needed to test the null hypothesis of market inefficiency (i.e. $\alpha_2 = -1$) for risk premium in Table 1.

Table 1 gives the estimate results of long-run relationship among Spot price (S_t), lagged futures price (F_{t-1}), risk premium (R_t) and convenience yield (μ_0) for the three oil products. It should note that we do not adjust the error term using GARCH model. Table 2 reports the results of cointegration tests, and it indicates that there is a cointegration relationship among these variables for all three oil products.

Some results can be obtained from Table 1, as follows:

(a) For WTI crude oil and unleaded gasoline futures markets, it is significant at 0.05 level to reject the joint hypothesis: $\alpha_1 = 1$ and $\alpha_2 = -1$ as well as the sole hypothesis: $\alpha_1 = 1$. This indicates that neither simple efficiency nor arbitrage equilibrium efficiency exist in the two markets. However, the futures prices have large forecasting function for the spot prices, and GDW tests imply the errors in eq. (7) are serially uncorrelated. In addition, there is convenience yield but not risk premium in the gasoline market, while the risk premium but not convenience yield exists in WTI crude oil market.

Table 1. Estimation of long-run relationship

	Parameters estimates			Testing statistics		
	$\bar{\mu}_0$	$\bar{\alpha}_1$	$\bar{\alpha}_2$	GDW	Q	LM
WTI crude Oil	0.07453 (0.346)	0.95213 (<0.0001)	-0.02919 (0.0323)	0.1798	0.0024	0.0060
	Test 1: $\bar{\alpha}_1 = 1$ and $\bar{\alpha}_2 = -1$ [0.0001]			0.2525	0.0080	0.0228
	Test 2: $\bar{\alpha}_1 = 1$ [0.0423], Test 3: $\bar{\alpha}_2 = -1$ [0.0001]			0.3400	0.0180	0.0533
				0.0967	0.0343	0.1040
				0.5132	0.0513	0.1670
Unleaded gasoline	0.24960 (0.0342)	0.93514 (<0.0001)	-0.00567 (0.705)	0.1163	0.3133	0.3225
	Test 1: $\bar{\alpha}_1 = 1$ and $\bar{\alpha}_2 = -1$ [0.0001]			0.9244	0.5987	0.5983
	Test 2: $\bar{\alpha}_1 = 1$ [0.0219], Test 3: $\bar{\alpha}_2 = -1$ [0.0001]			0.0004	0.7930	0.7940
				0.1299	0.3625	0.4450
				0.0746	0.4387	0.4303
Heating oil	0.12178 (0.2688)	0.96998 (<0.0001)	-0.00928 (0.5059)	0.3713	0.0108	0.0110
	Test 1: $\bar{\alpha}_1 = 1$ and $\bar{\alpha}_2 = -1$ [0.0001]			0.8493	0.0312	0.0215
	Test 2: $\bar{\alpha}_1 = 1$ [0.2614], Test 3: $\bar{\alpha}_2 = -1$ [0.0001]			0.0366	0.0649	0.0512
				0.1407	0.1226	0.0999
				0.1300	0.1661	0.1343

Remark. $\bar{\mu}_0$, $\bar{\alpha}_1$ and $\bar{\alpha}_2$ are the estimated values of the corresponding parameters in the regression: $\bar{S}_t = \bar{\mu}_0 + \bar{\alpha}_1 \bar{F}_{t-1} + \bar{\alpha}_2 \bar{S}_{t-1} \bar{r}_t + w_t$; numbers in parentheses are significance probability for the t -statistic, while numbers in brackets are significance probability for the F -statistic; all the numbers below statistics GDW (generalized Durbin-Watson), Q (Portmanteau statistic) and LM (Lagrange Multiplier) represent significance probability for respective statistic, and the lagged orders are all from 1 to 5.

Table 2. Cointegration tests

	a	b	p	AEG
WTI crude oil	no	no	0	-15.07*
Unleaded gasoline	no	no	2	-7.15*
Heating oil	no	no	0	-14.26*

Remark. Use AEG statistic and the Augmented Dickey-Fuller regression: $\Delta \bar{w}_t = a + bt + \gamma \bar{w}_{t-1} + \sum_{i=1}^p \lambda_i \Delta \bar{w}_{t-i} + \varepsilon_t$ to test the null hypothesis of no cointegration (i.e. $\gamma = 0$) among Spot price, futures price, risk premium and convenience yield, where $\bar{w}_t$ are the estimated residuals of the regression in Table 1; * indicates significance at 0.01.

(b) For heating oil market, it is significant at 0.05 level to reject the joint hypothesis:

$\bar{\alpha}_1 = 1$ and $\bar{\alpha}_2 = -1$, but not reject the two hypotheses $\bar{\alpha}_1 = 1$ and $\bar{\mu}_0 = 0$ at the significance of 0.2, respectively. This suggests the heating oil futures market is simple efficiency but not arbitrage equilibrium efficiency.

What could possibly explain above results? Why the three oil futures markets exhibit differences on market efficiency?

One possible explanation is that the crude oil prices fluctuate frequently from Jan 1986 to Dec 2004. In Table 1 Q and LM tests indicate that the errors have conditional heteroscedasticity for WTI crude oil in the observed period, so the structural relationship among spot price, lagged futures price, risk premium and convenience yield perhaps has changed. The changed structural relationship influences the accuracy of testing market efficiency. For gasoline and heating oil futures, they can utilize more information than crude oil market, for example, use crude oil futures price. Therefore, it does not have conditional heteroscedasticity of the errors in eq. (7) for the two oil products. Secondly, the speculative activities are more prevailing in the crude oil futures markets than refined oil markets. Hence, the risk premium is significant in WTI crude oil market but not in gasoline and heating oil markets. Finally, gasoline consumption is the largest in all of refined oil products in the world, so it comes easily forth shortage due to hoarding. Thus, gasoline storage possibly carries more convenience yield than the other two oil commodities for the holders.

Although the three oil futures markets present differences in the aspect of market efficiency, there is an identical point that the futures prices have large forecasting function for the spot prices.

3.2.2 A Nonlinear Analysis with GARCH Estimates

As the existence of conditional heteroscedasticity in WTI crude oil futures, we use eq. (7) to analyze the nonlinear relationship among these variables.

Table 3 gives the parameters estimates and relevant tests. Since the coefficient $\bar{\beta}_1$ is statistically significant at 0.05 level, the variance equation in eq. (7) is an ARCH(1) model. This implies the lagged errors impose a short-term influence to the conditional variance. The testing results in Table 3 do not support simple efficiency hypothesis or arbitrage equilibrium efficiency hypothesis.

Table 3. ARCH estimates for WTI crude oil

Parameters	$\bar{\mu}_0$	$\bar{\alpha}_1$	$\bar{\alpha}_2$	$\bar{h}_0$	$\bar{\beta}_1$
Estimates	0.0835 (0.1873)	0.9463 (<0.0001)	-0.0324 (0.0080)	0.008019 (<0.0001)	0.2303 (0.0166)
Tests	Test 1: $\bar{\alpha}_1 = 1$ and $\bar{\alpha}_2 = -1$ [0.0001], Test 2: $\bar{\alpha}_1 = 1$ [0.0039]				

Remark. The estimated model is eq. (7); numbers in parentheses and brackets are significance probability for the t -statistic and F -statistic, respectively.

3.3 Analysis by Stages

Since the errors of eq. (7) have conditional heteroscedasticity for WTI crude oil in the observed period, in order to discuss effectively the market efficiency in the futures market, it is a good way to divide the observed period into several appropriate stages.

According to the movement characteristic of the residuals in Table 2, we try to divide the observed period into three stages: the first stage from Jan 1986 to Sep 1990, the second stage from Oct 1990 to Nov 2000, and the third stage from Dec 2000 to Dec 2004.

Table 4 reports the parameters estimates and relevant testing statistics for each of the three stages. Q and LM statistics tests indicate that there is no conditional heteroscedasticity longer in the error series for each stage. This further suggests the division of three stages is reasonable. Table 5 shows the results of AEG tests, and it indicates that there is a cointegration relationship among these variables (spot price, lagged futures price, risk premium and convenience yield) for all the three stages.

Table 4. Cointegration analysis by stages for WTI crude oil

	Parameters estimates			Testing statistics		
	μ_0	α_1	α_2	GDW	Q	LM
The first stage	1.12499 (0.1337)	0.69407 (0.0003)	0.10268 (0.3618)	0.0046	0.0235	0.0559
	Test 1: $\alpha_1 = 1$ and $\alpha_2 = -1$ [0.0001]			0.0722	0.0577	0.1587
	Test 2: $\alpha_1 = 1$ [0.0939], Test 3: $\alpha_2 = -1$ [0.0001]			0.0630	0.1208	0.2960
				0.0148	0.2042	0.4485
The second stage	0.17903 (0.4867)	0.94259 (<0.0001)	0.00258 (0.9413)	0.1974	0.2953	0.5937
	Test 1: $\alpha_1 = 1$ and $\alpha_2 = -1$ [0.0001]			0.2002	0.6230	0.5323
	Test 2: $\alpha_1 = 1$ [0.3373], Test 3: $\alpha_2 = -1$ [0.0001]			0.0749	0.8196	0.7993
				0.1918	0.9333	0.9262
The third stage	0.07892 (0.7464)	0.91932 (<0.0001)	-0.06460 (0.0215)	0.3284	0.9747	0.9767
	Test 1: $\alpha_1 = 1$ and $\alpha_2 = -1$ [0.0001]			0.0944	0.9478	0.9772
	Test 2: $\alpha_1 = 1$ [0.2295], Test 3: $\alpha_2 = -1$ [0.0001]			0.4983	0.8152	0.9697
				0.3039	0.9444	0.7282

Remark. The meanings of the numbers in this table are analogous to Table 1.

Table 5. AEG tests by stages

	a	b	p	AEG
The first stage	no	no	0	-5.94*
The second stage	no	no	0	-10.49*
The third stage	no	no	0	-6.29*

Remark. The meanings of this table are analogous to Table 2.

Similarly, we can obtain some results about market efficiency in each stage from Table 4. The market efficiency is rather low in the WTI futures market in the first period, and the second stage supports simple efficiency hypothesis but not arbitrage equilibrium efficiency. However, the WTI futures market is semi-strong form efficiency (see [7]) in the third stage. These results imply that the market is more and more efficient and the speculators increasingly attach importance to risk premium.

4 Conclusions

In this paper, we present a modification for arbitrage equilibrium efficiency model, with introducing convenience yield and using lagged spot price to adjust risk premium. Empirical analysis indicates that there are significant differences about market efficiency in different oil futures markets: WTI and gasoline futures markets are neither simple efficiency nor arbitrage equilibrium efficiency, while heating oil futures market supports simple efficiency hypothesis. The analysis by stages for WTI futures market implies that the market is more and more efficient. Moreover, it is semi-strong form efficiency from Dec 2000 to Dec 2004.

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