Efficiency in the Crude Oil Futures Market

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ABSTRACT: This paper addresses the issue of "simple efficiency," which states that the futures price is an unbiased predictor of the spot price, in the case of trading in crude oil futures at NYMEX. This issue received considerable attention in the literature using cointegration analysis. This paper, however, explicitly deals with the crash in 1986, which is built into the analysis as a structural break following Perron (1989), and, more importantly, analyzes the trivariate system of spot-futures-posted prices in addition to bivariate spot-futures and spot-posted systems. The results indicate that the futures price of light sweet crude oil traded at NYMEX plays a significant role in price discovery. This observation is also supported by the widespread use of the futures price as a benchmark all over the world as well as by the decision of the U.S. Minerals Management Service to switch to the futures price from the posted price as the standard for calculating royalties.

I. INTRODUCTION

Historically, crude oil has been traded on the world market mostly under long-term contracts at "official" prices of exporting countries. Although spot markets for oil existed since the 1960s, trading in spot markets accounted for only 3 to 5 percent of the total trade before 1980. This share, however, reached 50 percent internationally and 20 percent in the U.S. during the first half of the 1980s. The shift toward the spot market was expedited by the second oil shock accompanying the Iranian Revolution, which rendered contract prices

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unreliable. Contract prices started to be adjusted so frequently that they were practically indistinguishable from spot prices. After the crash in 1986 major oil-exporting countries adopted "formula pricing" which tied contract prices to spot prices, calculating the former as the spot price of a certain benchmark crude oil, plus or minus an adjustment factor. For example, Saudi exports to the U.S. were priced based on the U.S. Gulf Coast spot price of Alaskan North Slope (ANS) until 1994, and based on West Texas Intermediate (WTI) spot price since then.

In March 1983, the New York Mercantile Exchange (NYMEX) introduced trading in a crude oil futures contract with delivery of light sweet crude oil at Cushing, Oklahoma. Although several streams are deliverable (including U.K. Brent, Norwegian Ekofisk, Algerian Saharan, and so on), the futures contract tracks WTI. During the first year, daily crude oil futures trading rose as high as 10,000 contracts and averaged around 6,000 (one contract involves the purchase or sale of 1,000 barrels). The success of the NYMEX experiment and the ending of official pricing by OPEC initiated the formation of a futures market for U.K. Brent at the International Petroleum Exchange (IPE) in the late 1980s. In the 1990s, crude oil futures have been in the top five contracts worldwide in terms of largest open interest.

The existence of three different price systems raises the possibility of arbitrage gains due to market inefficiency. Green and Mork (1991), based on the futures market literature about efficient contracts, test the following efficiency hypothesis: the official price used in long-term contracts is an efficient predictor of the spot price at the delivery date, and the two can differ only if there is a risk (or monopoly) premium. Green and Mork employ the generalized method of moments estimation technique to test this hypothesis in addition to more conventional time-series analysis of individual price series. They test for weak-form efficiency under a maintained hypothesis about the time-series behavior of the risk premium that they develop. Specifically, they test whether the contract-spot differential is correlated with its own past values before the determination of the current contract price. They also consider semi-strong efficiency for which they test for correlation with other relevant lagged information. They employ contract and spot prices for Mideast Light (a weighted average of Arabian Light, Iraq Basrah Light and Kirkuk) and African Light/North Sea (a weighted average of Nigerian Bonny Light, Algerian Saharan, Libyan Zuetina, U.K. Forties and Norwegian Ekofisk). Overall, their evidence does not support market efficiency during the 1978–1985 period, but when the sample is divided they observe increasing efficiency in the 1980s.

Although Green and Mork (1991) address the issue that official contract prices and spot prices are likely to be cointegrated, they do not treat this as evidence for market efficiency. Their hypothesis, however, clearly states that these two price series should not deviate from each other if the market is efficient. The existence of cointegration implies that one of these variables can be used to predict the other. The direction of this causal relationship is dictated in this case by the fact that the official (or contract) price is agreed upon before a spot price for the same product is formed, as the latter is determined at the delivery date. Therefore, the cointegration regression cannot be normalized arbitrarily; the spot price is the dependent variable and the contract price is the regressor. Specifically, the null hypothesis that the spot and contract prices are cointegrated with the cointegrating vector [1, -1] should be tested.

Given the increasing importance of oil futures trading and the decline of term contracts after the mid-1980s, other studies substituted the futures price for the contract price in the analysis of efficiency. Serletis and Banack (1990) apply cointegration tests to daily data from NYMEX (7/1/83–8/31/88) on spot-month and second-month futures prices for heating oil, unleaded gasoline and crude oil. They conclude in favor of market efficiency. However, as they do not test whether the cointegrating vector is [1, -1], the existence of a cointegrating relationship between the two price series cannot be taken as evidence of efficiency.

Quan (1992) who uses monthly data from January 1984 to July 1989 on spot, one-month-, three-month-, six-month-, and nine-month-ahead futures prices follows a similar approach. Spot and futures prices are found to be cointegrated for contracts of three months or less, but such a long-run relationship is rejected for longer-term futures contracts. Causality tests indicate that, contrary to popular belief, the information flow is from the spot price to the futures price. However, the spot-futures difference is directly tested for a unit root without a cointegrating regression. This imposes the cointegrating vector [1, -1]; but, by ignoring the constant of the regression, unbiasedness (or absence of a risk premium) is also imposed on the spot-futures relationship.

Moosa and Al-Loughani (1994), treating efficiency and unbiasedness together, address the same issue: the constant term in the cointegrating regression should not be significantly different from zero if the market is unbiased/efficient. Then, the null hypothesis of unbiasedness/efficiency is that the cointegrating vector is [1, 0, -1], with the additional restriction on the constant. Using monthly data on WTI crude oil spot, three-month- and six-month-ahead futures prices for the period of 1986:1-1990:7, Moosa and Al-Loughani test this hypothesis via cointegration analysis in addition to several other methods. They find that futures prices are neither unbiased nor efficient predictors of spot prices. A time varying risk premium is offered as the potential reason of the bias.

With the exception of Moosa and Al-Loughani's study, the coefficient restrictions are not tested and therefore evidence from these studies cannot be conclusive. Moosa and Al-Loughani's data start at January 1986 when prices were plummeting to historical lows. During the first half of 1986, prices dropped more than 50 percent. To have these months as the first few observations affects time series analysis of the spot-futures relationship, especially when one considers that they only use four and a half years of monthly data and that prices have a much different behavior in the rest of their sample. In this paper, the data period is extended backward to March 1983 (beginning of trading in oil futures at NYMEX) and forward to October 1995. Prices before the crash were $12–13 higher than prices after 1987, on average, and the downward trend of the early 1980s is replaced with a slight upward movement since 1987. The effects of this structural break on the data will be dealt with using techniques developed by Perron (1989). A further contribution of the present paper is the analysis of the role of posted prices. Although the importance of contract (or official) prices appear to have declined considerably over the years, posted prices (an indicator of seller's price—the U.S. analog of contract price) may still carry some relevant information, at least in the case of WTI. In order to investigate whether this is the case, the trivariate system of spot-contract-futures, in addition to bivariate systems of spot-contract and spot-futures, will be analyzed as well.

The rest of the paper is organized as follows. The hypothesis of simple efficiency and its relationship to the concept of cointegration is fully discussed in Section II. Section III presents the data, the econometric methodology and the results. Section IV concludes the paper.

II. THEORETICAL FRAMEWORK

Studies mentioned in the introduction test the hypothesis of 'simple efficiency' (or 'unbiasedness') which states that the futures price is an unbiased predictor of the spot price. This implies that:

$$S^{e}_{t,T} = F_{t,T} \tag{1}$$

where $F_{t,T}$ is the futures price of a contract that matures at time T and $S^{e}_{t,T}$ is the expected spot price at time T given all available information at time t. Assuming rational expectations and allowing for a risk premium whose presence can be tested, one obtains:

$$S_T = -a + F_{t,T} + e_{t,T} \tag{2}$$

where a is the mean value of the risk premium and $e_{t,T}$ is an error term representing the effects of news during the contract period.[1] The hypothesis of unbiasedness/efficiency is then tested by the following model:

$$S_T = \beta_0 + \beta_1 F_{t,T} + e_{t,T} \tag{3}$$

The null hypothesis to be tested is $[\beta_0, \beta_1]=[0,1]$. This cannot be tested using standard regression analysis as the series involved are nonstationary. Cointegration analysis provides a useful alternative. However, although cointegration is implied by the unbiasedness/efficiency hypothesis, the existence of a cointegrating relationship does not imply efficiency. The coefficient restrictions must be tested.

Green and Mork (1991) apply the theory for efficient contracts discussed above to the oil market by replacing the futures price with the contract (or official) price. However, as they acknowledge, since the period considered in their study (1978:1–1985:11), contract prices have lost credibility as both spot and futures markets have matured. Most exporters still announce official prices, but they are based on the spot price of some benchmark crude oil. Yet, these prices can still have some information to offer, especially in the case of WTI whose posted price is an indicator of the sellers' asking price and is not calculated based on a formula tying it to spot prices.

Moreover, Green and Mork provide evidence supporting the efficiency of contract prices as a predictor of spot prices while other studies show that the futures price is an unbiased/efficient predictor of the spot price. It seems appropriate to investigate the prediction capacity of the contract price and that of the futures price in a trivariate format of spot-futures-posted prices. In that direction, the following relationship is considered:

$$S_T = \beta_0 + \beta_1 F_{t,T} + \beta_2 C_T + e_{t,T} \tag{4}$$

where C_T is the contract (or posted) price. This trivariate system uses contemporaneous spot and posted prices; but in order to compare the predictive power of the futures price to that of the posted price, it seems more appropriate to use posted prices from the same period as futures prices. For example, last month's posted price should be compared with last month's one-month-ahead futures price to predict the current month's spot price. Therefore C_T is replaced by $C_{t,T}$ in our analysis. In this framework, if the futures price is a better predictor of the spot price, $F_{t,T}$ should be significant and $C_{t,T}$ should be insignificant, and vice versa if the posted price predicts the spot price better. If we find that $F_{t,T}$ ($C_{t,T}$) is significant and $C_{t,T}$ ($F_{t,T}$) is insignificant,[2] we test the null hypothesis that $[\beta_0, \beta_1]=[0,1]$ ($[b_0, b_2]=[0,1]$). If these restrictions are not rejected and the system is found to be cointegrated, then we conclude in favor of an efficient market. On the other hand, if both $F_{t,T}$ and $C_{t,T}$ are significant (or insignificant), this analysis will be inconclusive.

III. EMPIRICAL ANALYSIS

A. Data

Monthly crude oil futures prices for one-month-, three-month- and six-month-ahead contracts from NYMEX (light sweet crude oil—WTI) are calculated as the simple (not moving) average of daily data taken from Dow Jones on-line service. The data cover the period of 1983:3–1995:10 except for one-month-ahead contracts which starts at May 1983. Monthly spot and posted prices for WTI are taken from various issues of *OPEC Bulletin* and *Oil and Gas Journal*, respectively and cover the 1982:1–1995:10 period.[3]

B. Econometric Methodology[4]

In order to carry out cointegration tests, the nonstationarity of the series involved must first be established. The first step is to test the null hypothesis that each series is integrated of order one (denoted I(1)), i.e., they each possess a unit root. However, conventional unit root tests are not appropriate in the case of the oil market. As Perron (1989) showed, both analytically and empirically, structural breaks in stationary time series might induce apparent unit roots and cause unit root tests to lose power. Perron developed three models allowing for a one-time change in the level or in the slope of the trend function or in both. Actual testing involves including dummy variables for the break time in a standard Dickey-Fuller (1979, 1981) regression. The test statistic is a natural extension of Dickey-Fuller's standard unit root test statistic.

Two nonstationary series are said to be cointegrated if a stationary linear combination of the two series exists. A particularly interesting case occurs when the nonstationary series are integrated of order one, i.e., they each possess a unit root. If x_t and y_t are two I(1) series and they are cointegrated, there is a 'cointegrating parameter' b such that $z_t = x_t - by_t$ is I(0), or z_t is stationary. This is evidence of a long-run equilibrium relationship between x_t and y_t. Engle and Granger (1987) proposed to test for a unit root, using the standard Dickey-Fuller regression, in the residual series from the regression of x_t on y_t, which would be z_t. The test is modified to incorporate breaks in the trend function and critical values are calculated via Monte Carlo methods.

The standard errors obtained from a statistical package for the coefficient estimates of the cointegration regression are not correct as series involved are integrated of order one. Some type of correction is needed in order to test our coefficient restrictions. Moosa and Al-Loughani correct the standard errors following West (1988). However, since the present analysis explicitly treats the structural break in the trend, a more robust and general correction is preferred. Although there are several studies suggesting similar corrections, this paper follows the guidelines as described in pages 608–612 of Hamilton (1994). The

Table 1. Unit Root Test Results[a]

	Test statistic [b]	λ	*Critical values at 1% and 5%*
WTIC	-4.11 [4]	(.4)	-4.81, -4.22
WTIS	-3.97 [1]	(.3)	-4.78, -4.17
1-month	-3.19 [3]	(.2)	-4.65, -3.99
3-month	-2.23 [5]	(.2)	-4.65, -3.99
6-month	-2.49 [9]	(.2)	-4.65, -3.99

Notes: [a]Critical values are taken from Perron (1989).
[b]Numbers in squared brackets are the numbers of lagged differences used in augmenting the estimated equation.

process involves including lags and leads of the change in the regressor in the cointegrating regression and running an autoregression on its residuals. Then, a correction factor is calculated using the standard errors of these two regressions and the coefficient estimates of the autoregression. Once the t-statistics obtained from OLS is multiplied by this correction factor, one can use the standard critical values.[5]

C. Results[6]

Results of the unit root tests for the full sample size of each series are given in Table 1. Along with test statistics, the break fraction (λ) and corresponding critical values for each series are presented. Since the data indicate that all price series have a different mean as well as a different trend after the crash in 1986, two dummies, one for the level change and another for the slope change, are included. Also, there are large drops in prices for the first five-six months of 1986 and therefore the shock does not seem to be immediate. A third dummy is included to represent the non-instantaneous nature of the break. The month with the largest drop in price, which corresponds to February 1986 for most series, is chosen as the break time.

The results of cointegration tests for the efficiency hypothesis are reported in Table 2. The last column indicates that all four bivariate systems as well as the trivariate system including futures and posted prices lagged once are cointegrated. Consistent with the literature, the cointegrating relationship is stronger the shorter the term of the futures contract. One cannot reject the null hypothesis of no cointegration at the 1 percent significance level for three-month and six-month contracts in bivariate systems and not even at the 5 percent significance level for the same contracts in trivariate systems.

Coefficient estimates from the cointegrating regression are also reported. For bivariate systems, these are more in line with those of Serletis and Banack (1990) than those of Moosa and Al-Loughani (1994): b_0 is closer to 0 and b_1 is closer to 1. Contrary to Moosa and Al-Loughani, we cannot reject the coefficient restrictions implied by the efficiency hypothesis neither for futures prices nor for posted prices. Corrected t-statistics reported in Table 2 indicate that the hypotheses that $\beta_0 = 0$ and $\beta_1 = 1$ cannot be rejected.

The discrepancy between these results and those of Moosa and Al-Loughani is due to the larger data period and the explicit treatment of the structural break in the data in this analysis. Oil prices have different means and trends before and after the crash in early 1986. However, their data start at January 1986 when prices were plummeting to historical lows. During the first half of 1986, prices dropped from \$23-24 in January to \$8–9 in July. To have these

Table 2. Cointegration Test Results for the Efficiency Hypothesis[a]

Regressor(s)	b_0	b_1	b_2	*Test Statistic*
WTIC	0.006	0.869	—	-5.44 [1]
	(0.504)	(-1.191)		
F1(t-1)	-0.000	0.982	—	-9.01 [0]
	(-0.068)	(-1.328)		
F3(t-3)	-0.001	0.990	—	-4.52 [2]
	(-0.317)	(-0.246)		
F6(t-6)	-0.002	1.006	—	-4.61 [2]
	(-0.282)	(0.074)		
F1(t-1), WTIC(t-1)	0.000	0.941	0.042	-6.94 [1]
	(0.316)	(-1.334)	(1.002)	
F3(t-3), WTIC(t-3)	-0.000	0.929	0.073	-3.77 [4]
	(-0.045)	(-0.520)	(0.584)	
F6(t-6), WTIC(t-6)	0.001	0.813	0.226	-4.37 [1]
	(0.171)	(-0.858)	(1.236)	

Note: [a]Corrected t-statistics are given in parentheses. For bivariate systems, we test the null hypotheses that $\beta_0 = 0$ and $\beta_1 = 1$. In trivariate systems the null hypothesis that $\beta_2 = 0$ is also tested. Critical values at 1% and 5% for cointegration tests are -4.62 and -3.93 for WTIC; -4.84 and -4.08 for futures prices in bivariate systems; -5.27 and -4.50 for all trivariate systems.

months as first few observations affects time series analysis of spot and futures prices, especially when one considers that they only use four and a half years of monthly data and that prices had a much different behavior in the rest of their sample. When Moosa and Al-Loughani's analysis is repeated with the current data, results similar to those from their study are obtained. However, when the data period is extended to 1983:6–1995:10, b_0 becomes considerably smaller and actually less than one for three-month futures and b_1 becomes considerably larger and closer to one for both three- and six-month futures. When a further correction for the break in 1986 is carried out, the constant becomes virtually zero in both cases.

Overall, in bivariate systems both the posted price and the futures price are efficient/unbiased predictors of the spot price as all systems are found to be cointegrated and the coefficient restrictions cannot be rejected in any system. In order to determine whether one of these prices is superior to the other in information value, trivariate systems are estimated. These results are reported in last three rows of Table 2. It appears that futures prices dominate posted prices as b_1 is very close to 1 and b_2 is nearly 0 in all three specifications. Also, corrected t-statistics show that one cannot reject the null hypotheses that $\beta_0 = 0$, $\beta_1 = 1$ and $\beta_2 = 0$, i.e., the futures price has a coefficient not significantly different than one while neither the constant nor the posted price are significant. In short, the posted price does not seem to have any additional information to offer in order to improve spot price predictions. Taken together, these results indicate that posted prices have some information value but in very short horizons and that the futures market for the crude oil functions efficiently.

IV. CONCLUSION

The unbiasedness/efficiency hypothesis has received considerable attention in the literature in general and for trading in crude oil futures especially. This paper contributes to the analysis in several aspects. First, the time period of this study is much longer than other periods covered in any previous study, which improves time series analysis of the data. Second, oil prices have different means and trends before and after the crash of early 1986. This structural break is formally built into the analysis following the guidelines in Perron (1989). Finally, in addition to bivariate systems of spot-posted and spot-futures the relationship among all three price series is studied for the first time which provided a medium to compare the predictive power of futures price to that of posted price.

In bivariate systems, both the futures price and the posted price are efficient predictors of the spot price as both spot-futures and spot-posted systems are found to be cointegrated and coefficient restrictions cannot be rejected. Our analysis of trivariate systems shows that the futures price is superior to the posted price in predicting the spot price as the latter is insignificant and the former has a coefficient not significantly different than one in all specifications. Overall, we conclude that the WTI posted price has some information value but in very short horizons and that futures prices provide a superior and efficient predictor of the spot price.

Trading in crude oil futures has become quite popular in a very short period of time, especially after the crash in 1986. In the 1990s, crude oil futures have been in the top five contracts worldwide in terms of largest open interest. As of early 1997, light sweet crude oil traded in NYMEX had an average volume of about 100,000 contracts and an average open interest of about 400,000 contracts a day, securing the contract's popularity among the top five. At the same time, trading in Brent crude reached an average of about 50,000 contracts and an average open interest of over 150,000 contracts. The volume of trade in these futures markets is estimated to account for more than half of total oil trade in the world. The fact that these futures contracts reached such volume and share of the market in a relatively short period of time is significant, especially considering that there are about 100 trading institutions including spot, futures and informal markets. The popularity of futures trading is mostly due to its effective role as a price risk management tool for a variety of players in the world oil market from refineries to major oil companies. As a result of this widespread use of futures exchanges, many experts consider NYMEX and IPE oil futures prices as global benchmarks. The electronic trading at NYMEX through NYMEX ACCESS[SM] allows traders around the world to buy or sell even when the exchange is closed. Accordingly, crudes heavily traded in Asia such as Dubai Fateh or Malaysian Tapis are priced by adding fairly fixed spreads to closing prices of WTI and Brent contracts. In the U.S., the Minerals Management Service recently switched to futures price from the posted price as the standard for calculating royalties, providing another indication of how significant futures markets have become in discovering the price of oil. The results of this paper concur with this evaluation of the futures market.

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NOTES

1. For a more detailed discussion of the model, please refer to Moosa and Al-Loughani (1994) and references cited therein. The present paper's assumptions are the same as theirs and yield the same equation for testing. Therefore, one can compare the results with those in their paper.
2. Note that in either situation, equation (4) would become essentially equation (3).
3. Ideally, this analysis would be more informative if one could match the day for which the spot price data is available with the day of futures price data. However, there is no information about the day of the month for the spot data. The results, on the other hand, do not change significantly if beginning-of-month, mid-month or end-of-month futures price is substituted for the average price.
4. For detailed description of the tests, please refer to original articles cited and listed in references.
5. For details, please refer to Hamilton (1994) as well as the studies cited therein.
6. A referee of the *Journal of Energy Finance & Development* suggested that the testing of equations (3) and (4) should be conducted not on time-series form, but in cross-sectional data. However, the question of interest is whether the futures price is an unbiased estimator of the expected spot price "on a consistent basis" (i.e., month after month). This can be done by conducting time series analysis. Further, the analysis has covered three different time horizons of futures contract, which should shed some light on the cross-sectional aspect of the issue. Finally, this paper has borrowed the time series approach used by Moosa and Al-Loughani (1994), making the results of both studies easily comparable.

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