Two-Step Testing Procedure for Price Discovery Role of Futures Prices

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INTRODUCTION

Crude oil futures prices reflect the opinions of producers, consumers, and speculators about the prices of different commodities in the markets at a later date. To be of value to hedgers, the futures price must respond quickly and accurately to relevant new information. The ability of a futures market to process information has been investigated by many researchers. For instance, Bopp and Sitzer (1987) have studied the crude oil futures markets and find that, while near-term futures prices quoted one month ahead contain significant information about cash prices, longer-term futures prices, quoted more than one month ahead, do not convey information about the current spot price. The same conclusion is obtained by Bopp and Lady (1991) by using a different approach. Even though this conclusion is rather a popular belief, the validity and generality of their methodologies have to be questioned.

Their methodologies are basically the ordinary regression analysis that links futures and spot prices, or, lagged futures and spot prices. Their results, therefore, are reasonable only if two price series happen to satisfy the classic assumptions for the regression analysis. However, Yule (1926), Granger and Newbold (1974), and Phillips (1986) point out that the validity of the ordinary regression of two nonstationary variables may no longer be true, and there is a danger of possible spurious regressions. When this is the case, the correlation coefficient between two prices is meaningless. To avoid this problem, before estimating the models which link futures and spot prices to examine the price discovery role of futures prices, one has to be sure that both price series are stationary. If they are not, they must share the same nonstationary property. In other words, they are integrated of the same order. Furthermore, if some linear combination of them is stationary, then they are expected to move together in the long-run. The previous studies, however, fail to test such properties of futures and spot time series.

There is another problem with the previous studies. Most previous studies are based on an implicit hypothesis that there is a long-run stable relationship between

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the spot and futures prices. Without examining the validity of such a hypothesis, researchers have invented some models to study the "relationship" between the spot and futures prices. For instance, the previous approaches simply estimate the regression models (the cost pass-through and augmented price forecasting models) that link the spot and futures prices, failing to test the existence of such a linkage. However, if the generating mechanisms of these two time series are different, then no stable relationship can be expected between them. That is, the hypothesis implied in their analyses is rejected in the first place. Therefore, before studying the price discovery role, one has to determine if there is a long-run stable relationship between the spot and futures prices. That is, it must be established that the prices move together in the long run. When the price series are nonstationary of the same order and if some linear combination of them makes their nonstationary individual trend components cancel out, then a long-run relationship can be expected and they are referred to as being cointegrated.

Therefore, for the price discovery role of futures prices, a full testing procedure should consist of two steps. The first step is to test the existence of a long-run stable relationship between the spot and futures prices. To do this, the two price series are first checked for nonstationary of the same order. If they are nonstationary, they are examined then to determine whether they are cointegrated. The second step hinges on the results from the first one. If there is no strong statistical evidence to show the existence of such a relationship, because either the spot and futures prices are nonstationary of different order or they are not cointegrated, the investigation comes to an end because the two time series are generated completely independently, and it is impossible for one to provide any information for predicting the other. If the results from the first part reveal such a relationship, then the direction of causality (lead-lag) can be tested to examine the discovery role of futures prices.

In this article, following these two steps, the price discovery role of futures prices of crude oil is investigated. The monthly data (mid-month trading day) are obtained from *The Wall Street Journal,* from January 1984 to July 1989. The first step uses integration and cointegration tests to determine whether the crude oil spot and futures prices, which are nonstationary of the same order, are cointegrated. The second step consists of applying causality tests to those price series which pass the first test. The aim of this step is to determine whether the futures price leads the spot, or the spot leads the futures, and the direction of information flows.

The empirical results from this new approach reveal the following points. First, all spot and futures prices are nonstationary, which justifies the possibility of spurious regressions that simply link the spot and futures prices at their levels. Second, spot and futures are nonstationary of order one. As such, they all share the same generating mechanism. Third, spot and futures prices quoted less than or equal to three months ahead are cointegrated. Therefore, the long-run stable relationships (information flows) between them can be expected. On the other hand, spot and futures prices quoted more than three months ahead are not cointegrated. So, no long-run stable relationship can exist between them. This means that the relationship between spot and futures prices cannot be taken for granted. Fourth, contrary to popular belief, it is found that even though there are information flows between spot and futures prices quoted not more than three months ahead, the direction of such flows is from the spot price to the futures price.[1] This conclusion can be justified by examining the convergence rate of spot and futures markets. There is no

[1]This is a stronger conclusion than the one obtained in Bopp and Lady (1991) which asserts that spot prices have essentially the same forecasting power as futures prices.

doubt that the two markets differ from time to time. However, if the difference between them diminishes very quickly in the short-run (which is the case for the crude oil as shown later), people are not able to perceive this difference and tend to believe that the two markets move together. Consequently, they assume that futures prices can be used to predict spot prices.

INTEGRATION TEST

Many macroeconomic variables are often found to be nonstationary in levels. It is an empirical fact that these variables appear to be integrated of order one (stationary in the first differences), or to possess unit roots. Integration tests are designed to help evaluate the nature of the nonstationarity of economic variables, in other words, whether they are stationary in levels or in differences of some order. Therefore, it is necessary to test the stationarity and the nature of the stochastic movement of the prices.

An integration to test is used to examine the stationarity of the crude oil spot price and futures price. To form a long-run equilibrium relationship, the two variables must share the same intertemporal characteristics. That is, they must be integrated of the same order. The dynamic property of a single series can be described by how often it needs to be differenced to achieve time-invariant linear properties and provide a stationary process. A series that has at least invariant mean and variance and whose autocorrelation has "short memory" is called $I(0)$ or "integrated of order zero." If, on the other hand, a series needs to be differenced d times to become $I(0)$, it is said to be integrated of order d, denoted as $I(\mathrm{d})$.

The order of integration is inferred by testing for unit roots. Engle and Granger (1987) suggest seven unit root tests. Among them the augmented Dickey–Fuller (ADF) test is believed to be the most powerful test. The model for the ADF is given as

$$\text{ADF: } \Delta X_t = \alpha + \beta X_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta X_{t-i} + v_t \tag{1}$$

where $\Delta X_t = X_t - X_{t-1}$, and n is selected to be large enough to ensure that the residuals v_t are white noise. The ADF tests examine $H_0: \beta = 0$, the null hypothesis of unit root process against $H_1: \beta < 0$. The rejection of H_0 implies that the series X_t is stationary. The critical values for the t-statistics, obtained by Monte Carlo simulation, can be found in Fuller (1976) or Banerjee et al. (1991).

The ADF test statistics are reported in Table I. The results show that the null hypothesis (that all the series are nonstationary) cannot be rejected at the 5% significance level. Therefore, the spot and futures prices are nonstationary in the levels model. This nonstationarity raises the possibility of spurious regressions in the levels model and requires a test for stationarity in the rate of change model.

The next step is to then test the rates of change of all the variables to see whether they are stationary. Again, the ADF test is applied to the first-order differences of the spot and futures prices. The results are given in Table I. It is apparent that the hypothesis that the first-order differences of the prices is $I(1)$ rejected significantly and, therefore, all of the rates of change are stable. Thus, all the prices are integrated of the first order; that is, $I(1)$. This implies that the levels of crude oil spot price and each of the four futures prices show similar temporal properties. However, whether the levels of the spot price and futures prices are statistically linked over the long run has to be examined by the cointegration test.

Table I
ADF UNIT ROOT TEST: t-STATISTICS FOR $H_0: \beta = 0$

	Level	First-Order Difference
P_t	−1.70	−3.30
F_{1t}	−1.84	−4.47
F_{3t}	−1.87	−3.91
F_{6t}	−1.79	−3.54
F_{9t}	−1.55	−3.32

Model:

$$\Delta X_t = \alpha + \beta X_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta X_{t-i} + v_t$$

Note: The critical values for the one-sided ADF t-test at 5% significant level are:

$$\begin{matrix} -3.00 \\ -2.93 \\ -2.89 \\ -2.88 \\ -2.87 \\ -2.86 \end{matrix} \text{ when sample size } = \begin{cases} 25 \\ 50 \\ 100 \\ 250 \\ 500 \\ \infty \end{cases}$$

COINTEGRATION TEST

Suppose there are two economic variables which have the same nonstationary property. The question to ask is whether their individual long-run components could be canceled out by some linear combination of them and, if so, that they would move together in the long run. The cointegration test aims at detecting whether there exists a stable relationship between the levels of two economic variables. The assumption behind this test is that individual economic time series can be integrated of order one, $I(1)$, but certain linear combinations of the series may be stationary, that is, $I(0)$. This implies that a linear combination of a set of individually nonstationary economic variables may be stationary and, therefore, a long-run stable relationship between them can be expected. Formally, two variables, P_t and F_t, are said to be cointegrated if the difference $Z_t = P_t - F_t$, is integrated of order zero $I(0)$. Z_t is then stationary with a positive, finite spectrum at zero frequency. This is a rather special condition, because it implies that both series individually have extremely important long-run components. However, in forming Z_t, these long-run components cancel out and disappear . To do this, $Z_t = P_t - F_{jt}$ is tested as $I(0)$ rather than $I(1)$ by the ADF test.

Table II gives results of the test. It is clear that the only futures price variables with the ADF statistics being significant at the 95% level are the one- and three-month-ahead futures prices. This implies that the hypothesis that some linear combinations of the spot price and one-, and three-month-ahead futures prices are $I(1)$ can be rejected at the 5% significance level and a long-run stable relationship between the spot price and the futures prices can be expected. On the other hand, none of the other futures price variables has significant ADF statistics at the 95% level. Therefore, the hypothesis that the linear combinations between the spot price and these futures prices are $I(1)$ cannot be rejected at the 5% significance level, and one cannot expect a long-run stable relationship between them because they are separately generated. In this case also, one cannot expect that futures prices provide any information for predicting the spot price. This suggests that the long-run stable relationship between spot and futures prices cannot be taken for granted.

Table II
COINTEGRATION TESTS FOR CRUDE OIL SPOT AND FUTURES PRICES

Case 1[a]	Case 2[b]	Case 3[c]	Case 4[d]
−3.23	−3.62	−2.74	−2.42

[a]Spot price vs. one-month-ahead futures price.
[b]Spot price vs. three-month-ahead futures price.
[c]Spot price vs. six-month-ahead futures price.
[d]Spot price vs. nine-month-ahead futures price.
Model: Let $Z_{jt} = P_t - F_{jt}$, and apply ADF test for $\gamma = 0$

$$\Delta Z_{jt} = \alpha + \gamma_j Z_{t-1} + \sum_{i=1}^{n} \gamma_{i\Delta} Z_{t-i} + v_t$$

where $j = 1, 3, 6, 9$.

The findings that the spot price and the one- and three-month-ahead futures price of crude oil are $I(1)$, and a certain linear combination of them is $I(0)$, clearly demonstrates a long-run relationship between the spot price and the 1-, and 3-month-ahead futures prices. The result is not surprising. The further distant the period is into the future, the more fluctuations in both spot and futures markets are expected. As such, the short period ahead futures prices may move along the spot price, while the long period ahead futures prices may not, due to the greater uncertainty.

One needs now to determine which price leads and which price follows. This is addressed in the following sections. Since a long-run stable relationship is only found between the spot price and one- and three-month-ahead futures price, it is proper to study only these two price series.

GRANGER CAUSALITY TEST

The lead-lag relationship can be examined through Granger's causality test, which is designed to examine whether two cointegrated time series move one after the other or contemporaneously. When they move contemporaneously, one provides no information for characterizing the other.

Following Granger (1969), the simple causal model is

$$P_t = \sum_{i=1}^{m} \alpha_{1i} P_{t-i} + \sum_{j=1}^{m} \beta_{1j} F_{t-i} + e_{1t} \tag{2}$$

$$F_t = \sum_{i=1}^{m} \alpha_{2i} P_{t-i} + \sum_{j=1}^{m} \beta_{2j} F_{t-j} + e_{2t} \tag{3}$$

where P_t and F_t denote the spot and futures prices, respectively, and e_{1t} and e_{2t} are taken to be uncorrelated white noise.

If some of β_{1j} values are not zero, then F_t is said to Granger cause P_t. Similarily, if some α_{2i}'s are not zero, then P_t is said to Granger cause F_t. If the events both occur, then it is said that there is a feedback relationship between P_t and F_t. The usual F-test can be applied to test the null hypothesis that F_t fails to Granger cause P_t, i.e., $\beta_{1i} = 0$ for all i, or P_t fails to Granger cause F_t, i.e., $\alpha_{2i} = 0$ for all i.

Using the Akaike's final prediction error (FPE) criterion for determining the autoregressive lag length, Eqs. (2) and (3) are estimated for $m = 2$ by the least squares for one- and three-month-ahead futures prices. The significance of the restrictions,

$\beta_{1i} = 0$ and $\alpha_{2i} = 0$ are tested also. Table III summarizes the results. It is clear that the smallest significance levels at which the restrictions imposed on eq. (2) ($\beta_{1i} = 0$) for one- and three-month ahead prices can be rejected are 49% and 13%, respectively. This implies that one can be almost certain to accept the null hypothesis: $\beta_{1i} = 0$. This reveals that F_t fails to Granger cause P_t. In contrast, the smallest significance levels at which the restrictions on eq. (3) ($\alpha_{2i} = 0$) for the spot price, when one- and three-month-ahead prices are the dependent variables, can be rejected, are both 0.00%,—which implies that one can be almost certain to reject the null hypothesis: $\alpha_{2i} = 0$. This reveals that P_t Granger causes F_t. Together, it suggests that the spot price does Granger cause the futures prices, but not vice versa. This result can be explained by the fact that hedgers use the spot price to make decisions about futures prices. Futures prices are formed after the spot price is set in the markets. Hence, it is concluded that the spot market always leads the futures market and the crude oil futures price does not play an important role in price discovery. This conclusion, which is against the popular view that futures prices are able to provide information for predicting spot prices, can be explained by studying the convergence rate of the two markets through the Garbade and Silber approach.

THE GARBADE AND SILBER APPROACH

The essence of the price discovery function of futures markets hinges on whether new information is reflected first in changed futures prices or in changed cash prices. The Garbade and Silber approach provides a framework for analyzing whether one market is dominant in terms of information flow and price discovery. It proposes the following model of price behavior:

$$\begin{bmatrix} P_t \\ F_t \end{bmatrix} = \begin{bmatrix} \alpha_p \\ \alpha_f \end{bmatrix} + \begin{bmatrix} 1 - \beta_p & \beta_p \\ \beta_f & 1 - \beta_f \end{bmatrix} \begin{bmatrix} P_{t-1} \\ F_{t-1} \end{bmatrix} + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \tag{4}$$

where P_t and F_t are the logarithms of the spot price for month t and the futures prices for the same month. The constant terms, α_p and α_f, are added to eq. (4) to capture any secular price trends in the data and any persistent differences between spot prices, and futures prices that are attributable to different quotation conven-

Table III
CASUALITY ON CRUDE OIL AND FUTURES PRICES

	P_t	F_{1t}	P_t	F_{3t}
P_{t-1}	1.46	1.17	1.45	1.10
	(11.77)	(11.97)	(12.55)	(13.09)
P_{t-2}	−0.57	−0.94	−0.64	−0.94
	(−3.27)	(−6.794)	(−3.98)	(−8.43)
F_{t-1}	−0.01	0.067	0.259	0.66
	(−0.08)	(6.632)	(1.883)	(6.910)
F_{t-2}	0.11	0.12	−0.084	0.197
	(1.089)	(1.56)	(−0.867)	(2.70)
R^2	0.9962	0.9962	0.9962	0.9985
$\bar{R}^2$	0.9960	0.9960	0.9959	0.9984
Prob > $\|F\|$	49%	0.01%	13%	0.00%

tions. The coefficients, β_p and β_f reflect the influence of the lagged price from one market on the current price in the other market. Since the spot and futures market prices are for the same commodity, one would anticipate that both β_p and β_f are non-negative. The ratio $\beta_p/(\beta_p + \beta_f)$ can be used to examine the price discovery relationship between the two markets. If the ratio equals unity (so that $\beta_f = 0$), convergence of spot and futures prices occurs because the spot price always moves toward the futures prices. This is an extreme case where the spot market is a "pure satellite" of the futures market. If the ratio $\beta_p/(\beta_p + \beta_f)$ equals zero (so that $\beta_p = 0$), then the futures prices always adjust toward the spot prices and the futures market is a pure satellite. Intermediate values between zero and one imply mutual adjustments and feedback effects between the markets.

Eq. (4) can be solved for $F_t - P_t$ as a function of $F_{t-1} - P_{t-1}$ to yield:

$$F_t - P_t = \alpha + \delta(F_{t-1} - P_{t-1}) + e_t \tag{5}$$

where $\alpha = \alpha_f - \alpha_p$, $\delta = 1 - \beta_f - \beta_p$, and $e_t = u_t - v_t$. As can be observed in equation (5), δ reflects the speed of convergence between spot and futures prices. If δ is small, relatively little difference between futures and spot prices in month $t-1$ persists to month t. Therefore, prices will converge quickly.

Eqs. (4) are rearranged algebraically as follows, so that they can be estimated via ordinary least squares:

$$\begin{bmatrix} P_t - P_{t-1} \\ F_t - F_{t-1} \end{bmatrix} = \begin{bmatrix} \alpha_p \\ \alpha_f \end{bmatrix} + \begin{bmatrix} \beta_p \\ -\beta_f \end{bmatrix} [F_{t-1} - P_{t-1}] + \begin{bmatrix} u_t \\ v_t \end{bmatrix} \tag{6}$$

The estimates obtained with ordinary least squares are summarized in Table IV. $\beta_p/(\beta_p + \beta_f)$ represents the relative contribution of the futures market to the price discovery process and δ measures the rate of the convergence of futures and spot prices. Three results emerge. First, the estimates of β_f are significantly positive. This finding shows that the crude oil spot price leads the futures price in incorporating new pricing information. Second, the estimates of β_p are either negative or insignificant, suggesting that little feedback of pricing information occurs from the futures market to the spot market. The results here confirm the conclusion obtained in the above section. Third, the derived estimates of δ provide one possible explanation why people believe that futures prices can be used to predict

Table IV
ESTIMATED COEFFICIENTS FOR FUTURES AND SPOT PRICES: THE GARBADE AND SILBER APPROACH

Parameter	Case 1[a]	Case 2[b]
β_p	0.003	−0.053
	(0.031)	(−0.723)
β_f	0.480	0.310
	(7.423)	(4.982)
$\beta_p/(\beta_p + \beta_f)$	0.006	0.00[c]
δ	0.520	0.705

[a]Spot prices vs. one-month-ahead futures price.
[b]Spot price vs. three-month-ahead futures price.
[c]The calculated value is 0.05, but Garbade and Silber procedure requires that both b_p and b_f are positive.

Table V
ERROR CORRECTION MODEL

ECM with spot and one-month-ahead futures:

$$\Delta P_t = \underset{(0.581)}{0.044Z_{t-1}} - \underset{(0.198)}{0.033\Delta F_{t-1}} + \underset{(0.736)}{0.075\Delta F_{t-2}} + \underset{(2.954)}{0.454\Delta P_{t-1}} - \underset{(-0.672)}{0.162\Delta P_{t-2}}$$

$R^2 = 0.22,\quad \bar{R}^2 = 0.15,\quad SE = 1.70$

$$\Delta F_t = \underset{(0.901)}{0.054Z_{t-1}} - \underset{(-3.602)}{0.494\Delta F_{t-1}} - \underset{(-0.718)}{0.105\Delta F_{t-2}} - \underset{(-0.249)}{0.034\Delta F_{t-3}} - \underset{(-1.390)}{0.114\Delta F_{t-4}}$$

$R^2 = 0.76,\quad \bar{R}^2 = 0.702,\quad SE = 0.99$

ECM with spot and three-month-ahead futures:

$$\Delta P_t = \underset{(-0.140)}{-0.013Z_{t-1}} + \underset{(1.050)}{0.144\Delta F_{t-1}} + \underset{(0.421)}{0.044\Delta F_{t-2}} + \underset{(3.211)}{0.515\Delta P_{t-1}} - \underset{(-1.965)}{0.168\Delta P_{t-2}}$$

$R^2 = 0.23,\quad \bar{R}^2 = 0.16,\quad SE = 1.82$

$$\Delta F_t = \underset{(0.293)}{0.013Z_{t-1}} - \underset{(-2.844)}{0.389\Delta F_{t-1}} - \underset{(-0.963)}{0.091\Delta F_{t-2}} + \underset{(11.905)}{1.056\Delta P_{t-1}} + \underset{(1.273)}{0.223\Delta P_{t-2}}$$

$R^2 = 0.75,\quad \bar{R}^2 = 0.73,\quad SE = 0.79$

the spot. The estimates of δ are 0.520 and 0.705 for one- and three-month-ahead futures prices, respectively, indicating that only about 50% of the differential between one-month-ahead futures and spot prices in month $t-1$ persists to month t. For three-month-ahead futures contracts, about 30% of the differential diminishes from month $t-1$ to month t. This implies that arbitrage is undertaken rather quickly to bring about price convergence between the two markets. Therefore, market participants are not usually able to perceive the difference in the two markets and tend to believe that spot and futures prices move along together.

THE ERROR CORRECTION MODEL

Now that a long-run relationship between the crude oil spot price and the one-month-ahead futures price and the direction of the causality are established, the dynamics of the stochastic movement of this relationship can be studied now. Since the crude oil spot price and one-month-ahead futures price are cointegrated, an error correction model can be used to examine more closely the relationship between these two variables.

The error correction model (ECM) for cointegrated variables is commonly interpreted as reflecting partial adjustment of one variable to another. The concepts of cointegration and error correction are closely related. Indeed, it has been proven that two variables which are cointegrated have an error correction model representation. An error correction model for two variables relates the changes in the variables to lagged changes and a lagged linear combination of levels. The linear combination of levels which enters the error correction model is just that combination which is stationary in levels. In other words, when two variables are cointegrated, there always exists a valid error correction model for the data. An error correction model can be thought of as a description of the stochastic process by which the variables eliminate or correct the equilibrium error.

Consider the crude oil spot price P_t and one- and three-month-ahead futures prices F_t. It is known that both of them are integrated of order one and they are cointegrated. Define the difference $Z_t = P_t - F_t$ as the equilibrium error, which enters the error correction model:

$$\Delta P_t = -\gamma_1 Z_{t-1} + \sum_{i=1}^{m} \delta_{1i} \Delta P_{t-i} + \sum_{j=1}^{n} \theta_{1j} \Delta F_{t-i} + e_{1t} \tag{7}$$

$$\Delta F_t = -\gamma_2 Z_{t-1} + \sum_{i=1}^{r} \delta_{2i} \Delta P_{t-i} + \sum_{j=1}^{s} \theta_{2j} \Delta F_{t-j} + e_{2t} \tag{8}$$

where γ_1, γ_2, δ_{1i}, δ_{2i}, θ_{1j}, and θ_{2j} are coefficients, e_{1t} abd e_{2t} are assumed to be white noise.

A set of equations are estimated in a descending order of generality. Using the FPE criterion, different orders are determined for each equation and each futures price. The results are given in Table V. Two main conclusions follow from the error correction model. First, for eq. (7), when the first-order difference of the spot price is the dependent variable, all the lagged differences of futures prices are insignificant. On the other hand, for eq. (8), when the first-order difference of futures prices are the dependent variables, the lagged differences of spot price are very significent. This suggests that the spot price has much more explanatory power for futures prices than futures prices do for the spot. Second, overall, the estimated equation (8) for one- and three-month-ahead futures are much better than eq. (7) in terms of the R^2 (unadjusted and adjusted), the standard error, and the statistical significance of the model. This casts light on the lead-lag question, suggesting that eq. (8) should be used to study the dynamic relationship between spot and futures prices. One can conclude that the changes in futures price are well explained by the changes in the lagged spot prices and futures prices. Moreover, while the lagged spot prices play an important role in eq. (8), the changes in the lagged futures prices are not significant in eq. (7). It is found again that the spot market dominates the futures market, but not vice versa.

SUMMARY AND CONCLUSIONS

This article focuses on the role of price discovery of futures prices. It takes the crude oil market as an example and determines whether the crude oil futures price is capable of providing some relevant information for predicting the spot price. Some important conclusions are obtained.

This study proposes a two-stage testing procedure for determining the long-run relationship between two time series. It should ensure the existence of the relationship. The relationship itself can be studied only after the relationship is established. Most of the literature on studying the relationship between the futures market and spot market ignores the first step.

This two-step testing procedure is applied to the crude oil market. By implementing integration and cointegration tests, two conclusions are established. First, spot and all futures prices are nonstationary. This raises the possibility of spurious regressions. Second, only the spot price and one- and three-month-ahead futures price are cointegrated. This suggests that there is a stable long-run relationship between the spot and one- and three-month-ahead futures price; however, no such relationship is found for the spot and other futures prices. Attempts to study the relationship between the spot price and these futures prices are meaningless. Therefore, the procedure goes on to the second step using only the spot and one- and three-month-ahead futures prices.

Third, the Garbade and Silber approach and Granger causality test are applied to further investigate the price lead-lag relationships between the spot and one-month-out futures price. Both tests indicate that the crude oil spot price generally leads the futures price in incorporating new information, and that the crude oil spot market always dominates the futures markets. These results suggest that the crude oil futures price does not play a very important role in the price discovery process. However, because the two markets converge rather quickly, people tend to believe that futures prices move together with the spot. They believe also that futures prices are able to provide information for predicting spot prices.

Finally, an error correction model is used to study the dynamics of the relationship between spot and futures prices. The results show that changes in the lagged crude oil futures price do not effectively influence changes in the spot price, but vice versa. This provides further evidence that the crude oil futures price does not possess the price discovery function.

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