THE EFFECTIVENESS OF ARBITRAGE AND SPECULATION IN THE CRUDE OIL FUTURES MARKET

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INTRODUCTION

This article examines the relationship between contemporaneous spot and futures oil prices and the role of arbitrage and speculation in determining futures prices. In essence, the article is concerned with the behavior of the difference between contemporaneous futures and spot prices, or what is known as the basis. This is in contrast with testing efficiency (or unbiasedness) in which case the variables under consideration are the spot price and the lagged futures price,[1] the difference between which is known as the forecasting error.

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[1]Or the futures price and the expected spot price.

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While the efficiency of the oil futures market has been examined extensively,[2] the determination of the basis has received little attention, particularly on the empirical side. Stein (1961) presented a theoretical model for the determination of spot and futures stock prices which is based on the decision whether or not to hedge a position. Fama and French (1987) presented a detailed analysis of the behavior of the basis for 21 commodities that did not include oil. Two theories of the determination of futures prices were tested by Fama and French: the theory of storage, and the theory of risk premium. Bopp and Lady (1991) applied the same methodology to the oil futures market.

The objective of this study is to present a model for determining futures crude oil prices, showing the role of arbitrage and speculation in the process. Subsequently, this model is tested using the spot and the three-month futures prices of the West Texas Intermediate (WTI) crude oil. The objective of this empirical exercise is to give a quantitative dimension to the role of arbitrage and speculation in determining futures prices and, therefore, the basis. This study finds that during the period under investigation, arbitrage plays a more important role in this respect.

Before the model is presented it may be useful to spell out exactly what is meant by arbitrage and speculation. The main distinction between the two concepts pertains to risk. Speculation involves a deliberate assumption of risk, while arbitrage is a riskless operation. Arbitrage can be defined as "an investment strategy that guarantees a positive payoff in some contingency with no possibility of a negative payoff and with no net investment" [Dybvic and Ross (1992)]. Speculation is driven by capital gains in markets with sequential trading. Speculation may be defined as the action of buying and selling to profit by the rise or fall of prices [Tirole (1992)]. The application of these concepts to the crude oil market is illustrated after the model is presented.

THE THEORETICAL MODEL

The futures price of a storable commodity like crude oil is determined by the spot price and the cost incurred while the commodity is stored awaiting delivery some time in the future. This is the theory of storage which can be traced back to Kaldor (1939) and is found also in the work of Working (1953), Brennan (1958), and Tesler (1958). The cost associated with holding the commodity until the delivery date is known

[2]See, for example, Serletis and Banack (1990); Serletis (1991); Quan (1992); Nainar (1993); and Moosa and Al-Loughani (1994).

as the cost of carry. This item consists of the cost of storing oil in a tank (and perhaps insurance) and financial cost in the form of the opportunity cost of holding oil, or the cost of funding. But there may also be some benefits associated with holding the commodity. These benefits comprise what is known as the convenience yield. The convenience yield may arise from the use of the commodity as an input in a production process or if the demand for the commodity is highly volatile.[3] The theory of storage stipulates that there is an inverse relationship between the level of inventories and the convenience yield. This means that a constant convenience yield occurs only under very restrictive assumptions. In the case of crude oil, Gibson and Shwartz (1990) dispute the assumption of constant convenience yield and propose instead a stochastic representation for this variable. Moreover, Brennan (1958) argues that when the level of inventories is low, the marginal convenience yield may exceed the cost of carry and that makes the futures price lower than the spot price.

The basic assumption behind the model presented here is that the convenience yield is zero or negligible so that the net cost of carry is always positive. This may sound a heroic assumption if the previous arguments are borne in mind, but it can be justified if one assumes that speculators and arbitrageurs are not interested in and do not use the commodity "per se." Rather, it is assumed that speculators and arbitrageurs, to use Brennan's (1958) words, merely possess titles to inventories. Given that market participants hold inventories for the purpose of meeting the obligations dictated by futures contracts or for speculative motives, and not to use them as an input in a production process, convenience yield is unlikely to arise.[4] Another implication is that the level of inventories is unlikely to change, particularly if it is associated with the specifications of the futures contract. This implication again leads to the same conclusion of zero convenience yield, as Brennan (1958) argued that "the marginal convenience yield is zero in the peak storage months." The assumption of zero convenience yield has been used in empirical studies of this kind. For example, Bopp and Lady (1991) specified a function in which the futures price is linearly dependent on the spot price and time which is taken to be a proxy for the cost of carry. The implication of their model is that the net cost of

[3]Brennan (1958) argues that commodities provide a yield that must be deducted from storage costs proper to calculate net storage cost.

[4]It is difficult, for example, to believe that a financial institution dealing in the oil futures market may use the inventories to which it possesses a title to run the central heating system in its offices and derive a convenience yield from that.

carry is positive which means either that convenience yield is zero or that it is less than the cost of carry.

Bearing in mind this argument and assuming that the oil market is perfectly efficient and that there are no sharp price movements, the futures price would differ from the spot price by an amount equal to the cost of carry. This spot/futures pricing relationship is based on the assumption that market participants are able to trade in the spot and futures market simultaneously, i.e., they can utilize spot/futures arbitrage. Let S_t be the spot price, F_t the futures price determined now for delivery in period $t + 1$, and C_{t+1} the cost of carry which is incurred during the holding period $t + 1$. If

$$F_t > S_t + C_{t+1} \tag{1}$$

then it will be profitable to buy spot, store the oil (incurring C_{t+1} in the process), and sell futures. Net profit, N, will be given by

$$N_{t+1} = F_t - (S_t + C_{t+1}) \tag{2}$$

Attempts by market participants to earn profit would put upward pressure on the spot price and downward pressure on the futures price until profit is eliminated, in which case the motive for arbitrage disappears. Similarly, if

$$F_t < S_t + C_{t+1} \tag{3}$$

then it will be profitable to sell spot and buy futures, and this will create upward pressure on the futures price and downward pressure on the spot price. In equilibrium, therefore, the following equation must hold

$$F_t = S_t + C_{t+1} \tag{4}$$

Equation (4) is known as the arbitrage equation which implies that arbitrageurs have no incentive to buy or sell futures contracts. In this case the basis, B_t, is given by

$$B_t = F_t - S_t = C_{t+1} \tag{5}$$

Given, by assumption, that $C_{t+1} > 0$, it follows that $B_t > 0$. This is the case if the futures price is determined purely by arbitrage.

Arbitrage on its own may not be adequate to explain the behavior of futures prices and, therefore, the basis, because futures prices may embody expectations about spot prices. It is important to remember that for eq. (4) to hold, two assumptions must be valid: (1) infinite elasticity of the demand for futures contracts and (2) arbitrage funds do not run out. If these conditions do not hold, then factors other than arbitrage will affect the futures price. Moreover, if market participants believe that some factors will affect the spot price expected to prevail in the future, S^e, then the pricing equation will be

$$F_t = S_t + C_{t+1} + \rho_t \tag{6}$$

where ρ_t is the risk premium such that $\rho_t >< 0$, depending on how market participants (more specifically, speculators) expect events to affect prices.

The role of speculation (which is based on expectation) may be illustrated as follows. If $S_t^e > S_t$ it will be profitable to buy and hold, in which case S_t will rise to eliminate the advantage of holding the marginal unit. If, on the other hand, $S_t^e < S_t$ speculators will sell spot, putting downward pressure on S_t. Given the arbitrage equation, this behavior should affect the futures price as well. The basis in this case is given by

$$B_t = F_t - S_t = C_{t+1} + \rho_t \tag{7}$$

If $\rho_t < 0$ and $|\rho_t| > C_{t+1}$ it follows that $B_t < 0$. Therefore, $B_t >< 0$.

Thus, both arbitrageurs and speculators play roles in determining futures prices. There is, however, another category of participants who might also influence the price: these are the hedgers. Hedging arises out of the need for protection against the risk of spot price fluctuations, given that transactions are normally contracted months before the payments for or receipt of shipments. However, it can be argued that hedgers can be classified either as arbitrageurs or as speculators,[5] although this proposition is not universally acceptable. Van Belle (1973), for example, argues that failing to account explicitly for the role of hedgers will bias the estimates of the weights attributed to speculation and arbitrage. On the other hand, Tsiang (1959) does not distinguish between hedging and speculation if the latter is defined in a "narrow sense." If hedging is defined as a sale or a purchase of futures contracts to reduce the open position of the trader, then this is similar to speculation. Stoll's (1968) argument that the futures price is determined by arbitrage and speculation is applied in what follows.

A DIAGRAMMATIC EXPOSITION

This exposition illustrates the role and relative effectiveness of arbitrage and speculation in determining futures prices. It is assumed that

[5]See, for example, Stoll (1968).

arbitrageurs and speculators have downward sloping excess demand functions for futures contracts. Arbitrageurs' demand depends on the difference between the level of the futures price determined by the arbitrage equation, $\overline{F}$, and the actual forward price, F. Thus, if $F = \overline{F}$ arbitrageurs have no incentive to buy or sell futures contracts, i.e., their excess demand is zero. Speculators' demand, on the other hand, depends on the difference between the expected spot price, S^e, and the actual futures price. Thus, if $F = S^e$ speculators have no incentive to buy or sell futures contracts, i.e., their excess demand is zero. In this diagrammatic exposition, it is assumed that $S^e < F < \overline{F}$ so that arbitrageurs are net buyers of futures contracts (positive excess demand) while speculators are net sellers (negative excess demand).[6] For equilibrium, net buying by arbitrageurs must be equal to net selling by speculators. Figure 1 and Figure 2 can be used to demonstrate the following. If the case of infinitely elastic excess demand by arbitrageurs is disregarded, the effectiveness of arbitrage and speculation depends on the relative elasticities of the two demand functions. Diagrammatically, this is represented by the relative slopes of the arbitrageurs' and speculators' excess demand curves which, for simplicity, are called the arbitrage and speculation schedules.

In Figure 1, the slope of the arbitrage schedule AA is kept unchanged, while the slope of the speculation schedule SS is varied by rotating it around its point of intersection with the price (vertical) axis. To start, consider the schedules AA and S1S1. This combination gives an arbitrage futures price, $\overline{F}$; an expected spot price, S^e; and an equilibrium futures price, $F1$. The market is in equilibrium because the quantity of futures contracts bought by arbitrageurs, QA1, is equal to the quantity sold by speculators, QS1. Since $F1$ falls half way between $\overline{F}$ and S^e, this implies that arbitrage and speculation have similar roles or weights in determining futures prices. This situation arises because AA and S1S1 have the same slope. A situation of arbitrage dominance arises when the speculation schedule (S2S2) is steeper than the arbitrage schedule, giving an equilibrium futures price of $F2$ which is closer to $\overline{F}$. Alternatively, a situation of speculation dominance arises when the speculation schedule (S3S3) is less steep than the arbitrage schedule.

In Figure 2, the slope of the speculation schedule is kept unchanged while the slope of the arbitrage schedule is varied by rotating it in such a

[6]This assumption, however, need not be the case. Any other assumption does not change the exposition or affect the conclusions derived from it.

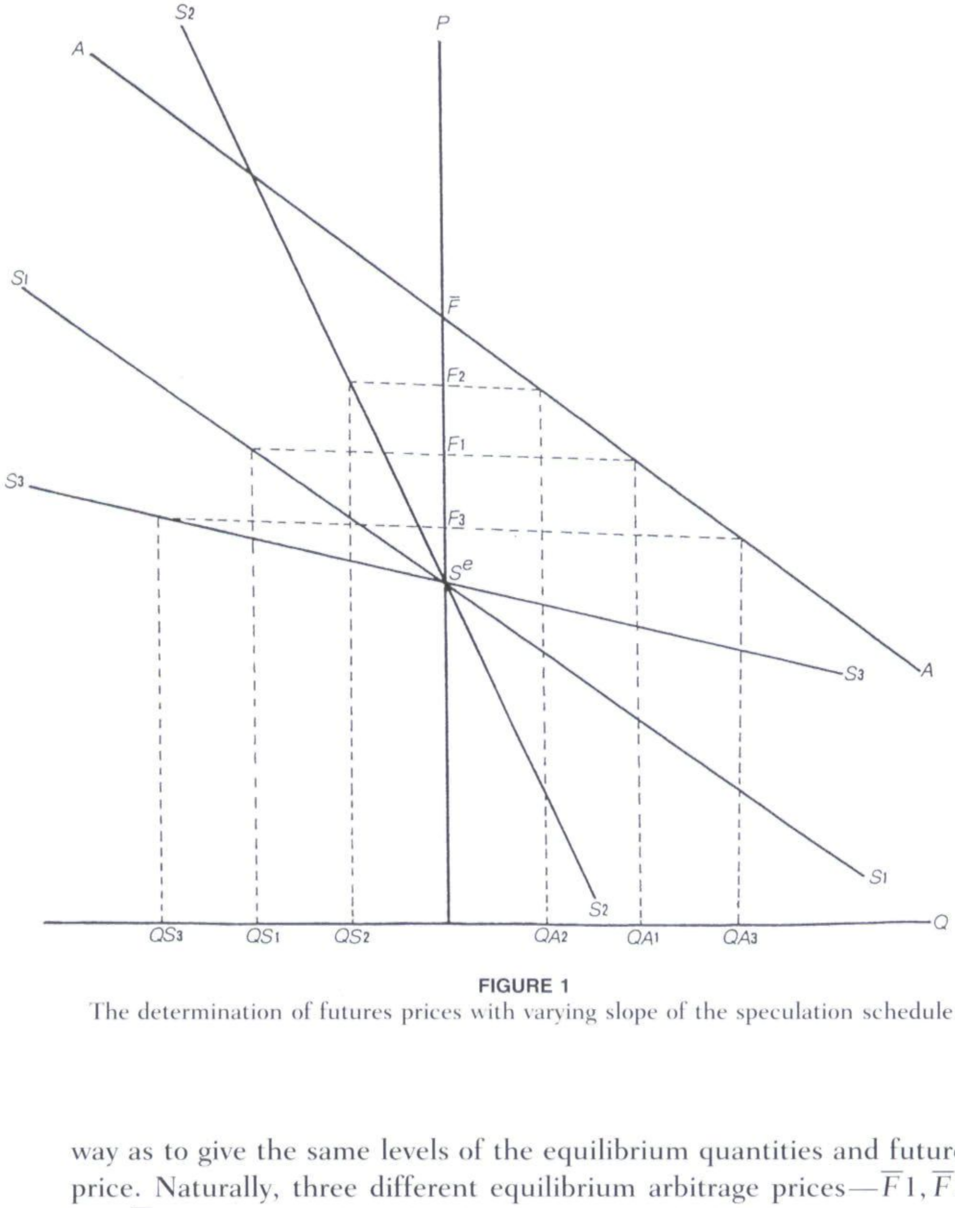

FIGURE 1
The determination of futures prices with varying slope of the speculation schedule.

way as to give the same levels of the equilibrium quantities and futures price. Naturally, three different equilibrium arbitrage prices—$\overline{F}1, \overline{F}2$, and $\overline{F}3$—correspond to the three arbitrage schedules—A1A1, A2A2, and A3A3. However, the conclusion is unchanged. When the two schedules have equal slopes, F falls half way between $\overline{F}1$ and S^e, implying equal roles for arbitrage and speculation. When the arbitrage schedule (A2A2) is flatter than the speculation schedule, F is closer to $\overline{F}2$ than to S^e, implying arbitrage dominance. When the arbitrage schedule (A3A3) is steeper than the speculation schedule, F is closer to S^e than to $\overline{F}3$, implying speculation dominance.

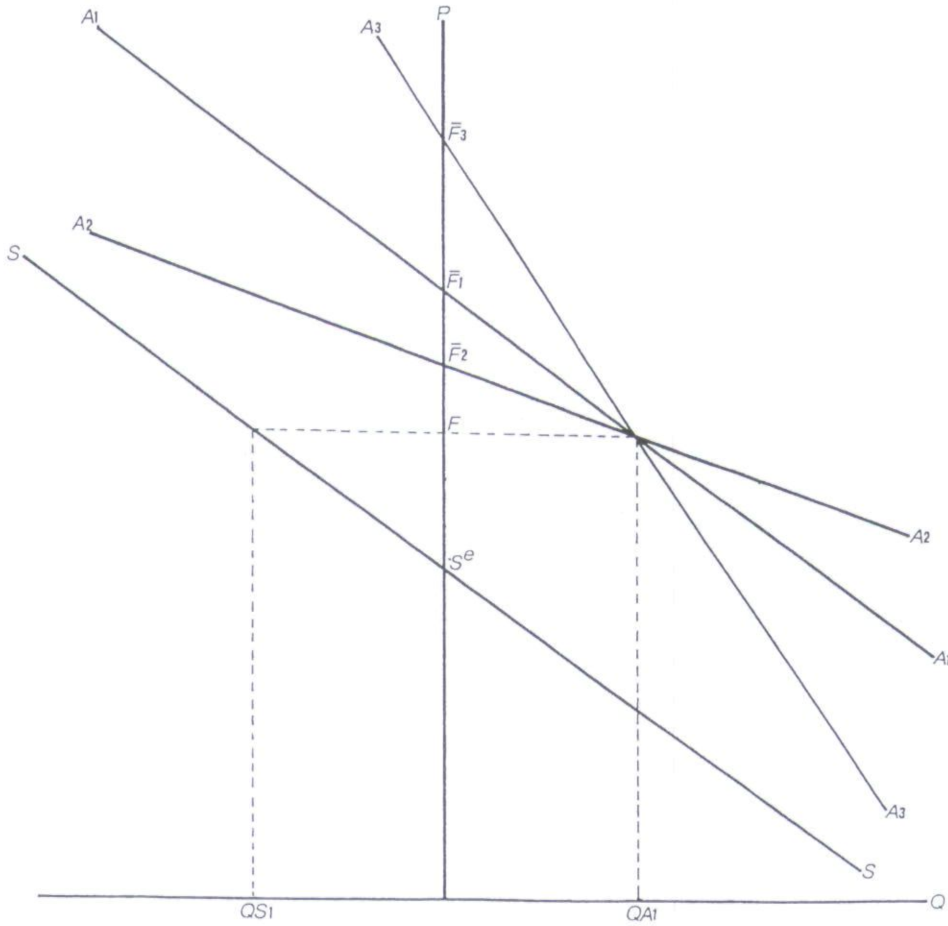

FIGURE 2
The determination of futures prices with varying slope of the arbitrage schedule.

MODEL SPECIFICATION

In this section the model is specified in a testable form in which all variables are measured in natural logarithms.[7] The starting point is to specify excess demand functions for arbitrage and speculation, which may be written as

$$Q_t^a = \alpha_a(\overline{F}_t - F_t), \qquad \alpha_a > 0 \tag{8}$$

[7]One reason for specifying the model in natural logarithms is to avoid any problem associated with the definition of expected variables in levels. Strictly speaking, this specification requires nonlinear excess demand functions of the form $Q^a = \delta_a(\overline{F}/F)$ and $Q^s = \delta_s(S^e/F)$ so that a log-linear transformation produces eqs. (8) and (9). This is also the procedure adopted by economists examining this relationship in the foreign exchange market [see, for example, Kesselman (1971), Haas (1974), McCallum (1977); Callier (1981); Moosa and Bhatti (1994)].

$$Q_t^s = \alpha_s(S_t^e - F_t), \qquad \alpha_s > 0 \tag{9}$$

such that $\overline{F}_t$ is the arbitrage futures price derived from eq. (4). In equilibrium, there is zero excess demand, i.e.,

$$Q_t^a + Q_t^s = 0 \tag{10}$$

which implies that

$$F_t = \left[\frac{\alpha_a}{\alpha_a + \alpha_s}\right]\overline{F}_t + \left[\frac{\alpha_s}{\alpha_a + \alpha_s}\right]S_t^e \tag{11}$$

Equation (11) shows that F_t can deviate from $\overline{F}_t$ whenever α_s is not dominated (in terms of magnitude) by α_a and when $\overline{F}_t \neq S_t^e$.

It is also possible to specify an excess demand function for hedgers as

$$Q_t^h = \gamma - \alpha_h F_t, \qquad \gamma, \alpha_h > 0 \tag{12}$$

In this case, the equilibrium condition is given by

$$Q_t^a + Q_t^s + Q_t^h = 0 \tag{13}$$

or

$$F_t = \frac{\gamma}{\alpha_a + \alpha_s + \alpha_h} + \left[\frac{\alpha_a}{\alpha_a + \alpha_s + \alpha_h}\right]\overline{F}_t + \left[\frac{\alpha_s}{\alpha_a + \alpha_s + \alpha_h}\right]S_t^e \tag{14}$$

McCallum (1977) argues that if γ and α_h are small, eq. (14) is not distinguishable from eq. (11). Given this argument and the previous arguments for regarding hedging either as speculation or as arbitrage,[8] the model can be written in a testable form as

$$F_t = \beta_0 + \beta_1\overline{F}_t + \beta_2 S_t^e + \varepsilon_t \tag{15}$$

where β_1 and β_2, respectively, indicate the relative importance of arbitrage and speculation in determining futures prices. The restrictions implied by the model are $\beta_0 = 0$, $\beta_1 > 0$, $\beta_2 > 0$ and $\beta_1 + \beta_2 = 1$. The closer β_1 is to unity, the less important is speculation. If β_1 turns out to be close to 1 but significantly different from it, this means that

[8]In relation to the oil market, Kumar (1992) implicitly favors this procedure by distinguishing between hedging and speculation on the one hand, and arbitrage on the other. Specifically, he states that "futures markets serve two interrelated purposes: (1) hedging or speculation; and (2) participants' expectations with respect to the future course of prices."

arbitrage exerts a strong influence on the futures price without achieving arbitrage equilibrium as indicated by eq. (4). If the effect of speculation is discarded, eq. (15) reduces to

$$F_t = \beta_0 + \beta_1 \overline{F}_t + \varepsilon_t \tag{16}$$

which can be used to test the arbitrage eq. (4). For eq. (4) to be valid, the restriction $(\beta_0, \beta_1) = (0, 1)$ must hold.

THE BEHAVIOR OF SPOT PRICES, FUTURES PRICES, AND THE BASIS

This model is tested using a sample of monthly observations covering the period January, 1986 to December, 1991. S_t and F_t are represented by the spot and 3-month futures prices of the WTI crude traded on NYMEX as reported by Parra Associates.[9]

Figure 3 shows the behavior of spot and futures prices over the sample period. It shows that this crude was selling sometimes at a premium and other times at a discount relative to the spot price. This is demonstrated also by Figure 4. If the assumption $C_{t+1} > 0$ is

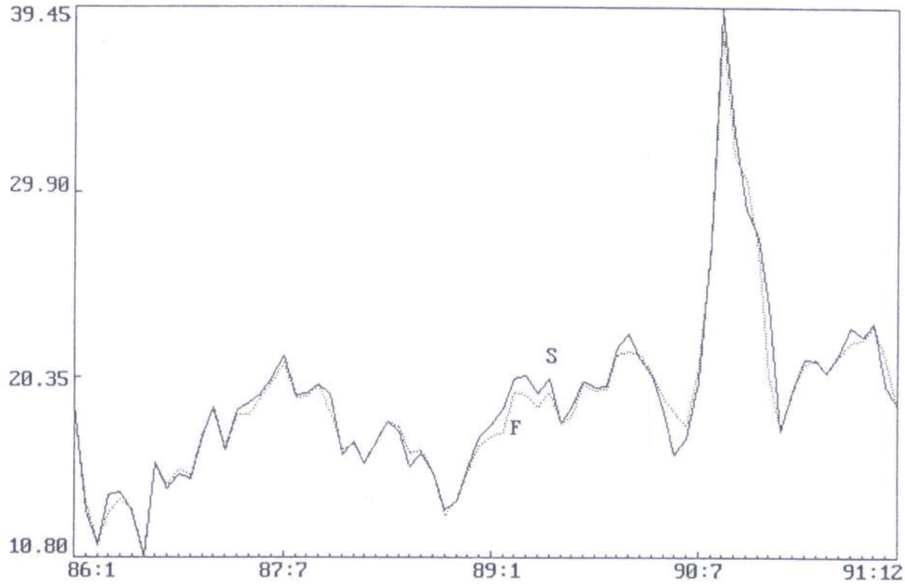

FIGURE 3
Spot and three-month futures prices of WTI crude (dollars/barrel).

[9]F. R. Parra Associates and Middle East Economic Survey, *International Crude Oil Prices: Major Time Series from the 1960s to 1991*, Middle East Petroleum and Economic Publication, Nicosia, January, 1993.

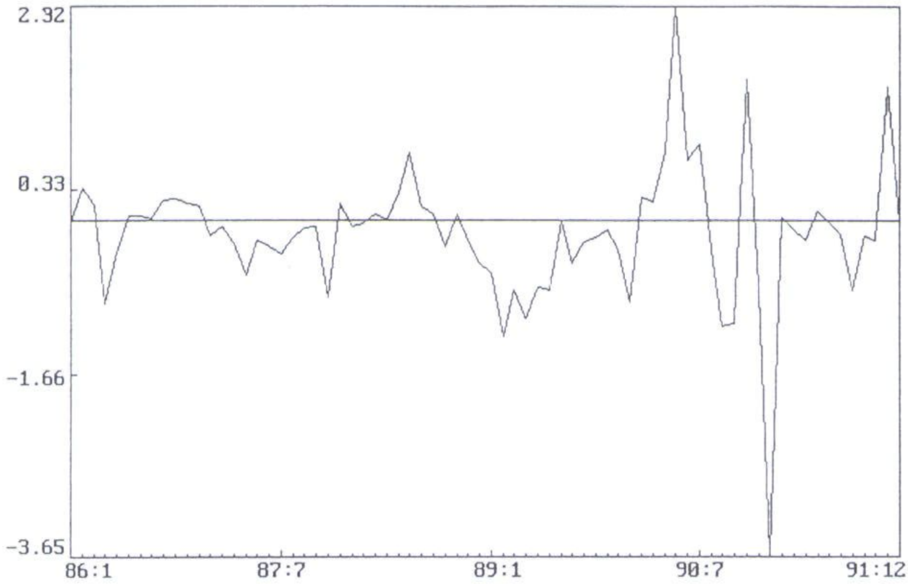

FIGURE 4
The basis (dollars/barrel).

maintained, then, given that $B_t >< 0$, as shown by Figure 4, it must follow that $\rho_t >< 0$, i.e., over the sample period, speculation played a role in determining futures prices.

The basic statistics of the basis (measured in dollars per barrel) are presented in Table I. Figure 5 also shows that the basis was not serially correlated and random. It is obvious that while the basis was small on average (a mean value of -0.14), it has been rather erratic. This may be taken to indicate that while speculation played a role, it was a rather small role.

TABLE I
Basic Statistics of the Basis ($B_t = F_t - S_t$)

Maximum	2.32
Minimum	−3.65
Mean	−0.15
Standard deviation	0.72
Coefficient of variation	4.97
Skewness	−0.87
Kurtosis-3	8.22

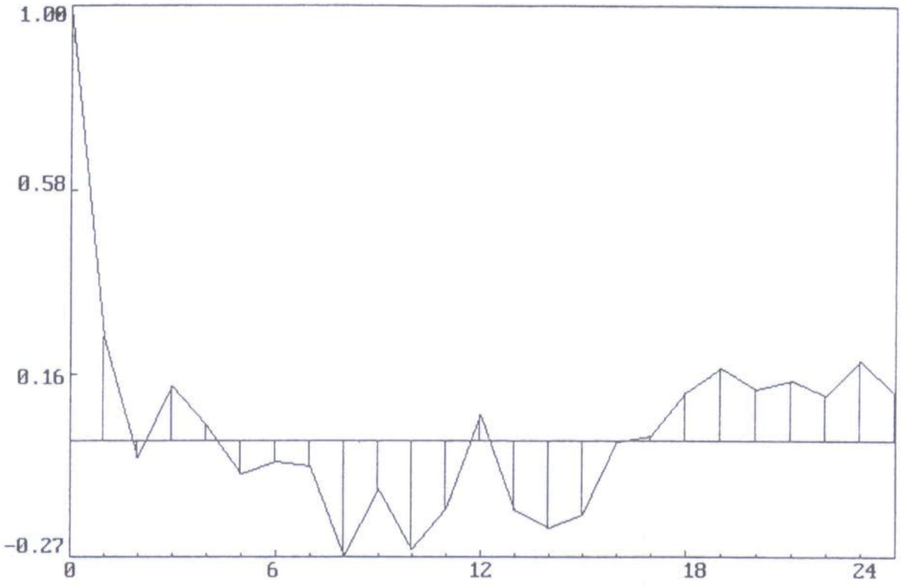

FIGURE 5
Autocorrelation function of the basis.

MEASUREMENT PROCEDURES

Before the empirical results are presented, it is important to demonstrate the procedures used to measure the two variables, $\overline{F}$ and S^e. The equilibrium futures price, $\overline{F}$, is determined by eq. (4) by assuming the following

$$C = C^r + C^f \tag{17}$$

where C^r is the real cost of carry (storage, etc.) and C^f is the financial cost of carry (opportunity cost or cost of funding). The real cost of carry is assumed to be determined by the latest (the previous month's) inflation rate. For this purpose, the inflation rate is defined as the month-to-month change in OECD consumer prices. The financial cost of carry is proxied by the three-month Eurodollar interest rate (LIBOR). Thus

$$\overline{F}_t = S_t(1 + \pi_{t-1})(1 + R_t) \tag{18}$$

such that

$$\pi_t = 3\left[\frac{P_t}{P_{t-1}} - 1\right] \tag{19}$$

where π is the month-to-month inflation rate,[10] P is the OECD consumer price index, and R is interest rate adjusted to cover a period of three months.[11] Both of these time series are from the IMF's *International Financial Statistics*. The cost of carry, as measured by $\overline{F}_t - S_t$, is plotted in Figure 6 superimposed on the basis, $F_t - S_t$. This graphical representation demonstrates the interaction between arbitrage and speculation.

The second point to be considered in this section is how to proxy the expectations variable, S_t^e, which is the spot price expected to prevail at the time of the maturity of the futures contract. In this kind of analysis, several expectation formation mechanisms have been used: adaptive expectations [e.g., Stoll (1968)]; extrapolative and regressive expectations [e.g., Kesselman (1971) and Haas (1974)]; rational expectations [e.g., McCallum (1977) and Callier (1981)], Fisherian expectations [e.g., Kohlhagen (1979)] and ARIMA representation [e.g., Stokes and

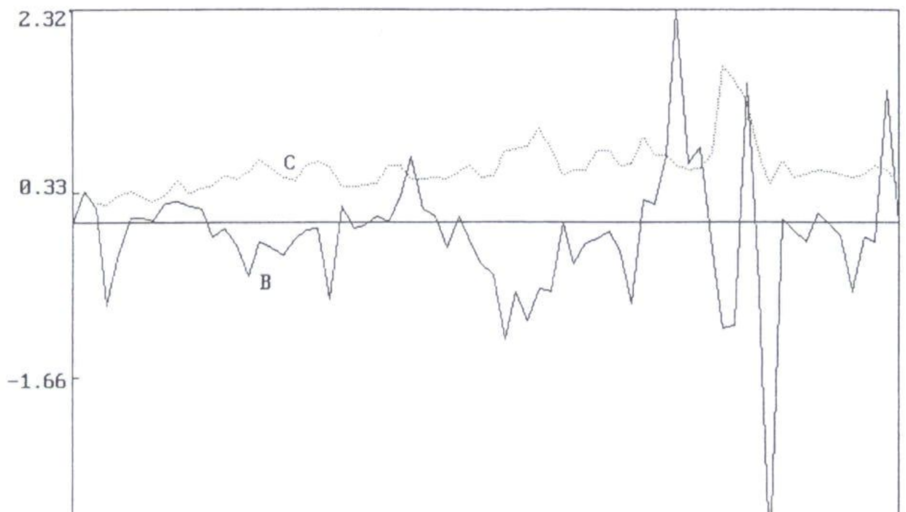

FIGURE 6
The basis (B) and the cost of carry (C).

[10]The lagged inflation rate is used because it is assumed that the real cost of carry, which is fixed in advance for the coming holding period, is determined by the latest available monthly inflation rate. This is assumed to be the previous month's inflation figure.

[11]Bopp and Lady (1991) tried to measure the cost of carry implicitly by regressing the futures price on a constant, the spot price, and a time variable reflecting the maturity of the futures contract. They did not attempt to measure the actual components of the cost of carry. Fama and French (1987), on the other hand, only recognized the financial cost of carry by regressing the basis (as a percentage of the spot price) on interest rate and seasonal dummies.

Neuburger (1979)].[12] The method used here is an expectations formation mechanism that is similar to but less stringent than rational expectations. Let the expected value of the spot price be equal to the mathematical expectation, conditional on the information set available when the expectation is formed. This is represented by

$$S_t^e = E(S_{t+1} \mid \Omega_t) \tag{20}$$

where E is the expected value operator and Ω_t is the relevant information set. The actual value of the spot price, which will prevail at the maturity of the futures contract, is given by

$$S_{t+1} = E(S_{t+1} \mid \Omega_t) + w_{t+1} \tag{21}$$

such that $E(w_{t+1} \mid \Omega_t) = 0$. Thus, it is possible to derive the relationship

$$S_t^e = S_{t+1} - w_{t+1} \tag{22}$$

where w_{t+1} is the expectations error which is realized at time $t + 1$. If eq. (22) is substituted into eq. (15) the following equation is obtained

$$F_t = \beta_0 + \beta_1 \overline{F}_t + \beta_2(S_{t+1} - w_{t+1}) + \varepsilon_t \tag{23}$$

or

$$F_t = \beta_0 + \beta_1 \overline{F}_t + \beta_2 S_{t+1} + u_{t+1} \tag{24}$$

where $u_{t+1} = -\beta_2 w_{t+1} + \varepsilon_t$. If, as assumed, $w_{t+1} \sim I(0)$, then $u_{t+1} \sim I(0)$ if $\varepsilon_t \sim I(0)$. This means that cointegration in (15) implies cointegration in (24).[13]

Because of the use of monthly data and the three-months futures price, S_{t+1} is replaced by S_{t+3}. Thus, when eq. (15) is estimated, S_t^e is proxied by S_{t+3}. This creates the problem of overlapping data which induces an MA(2) process in the empirical residuals of the cointegrating regressions. One could use quarterly data, but that would reduce the sample size, creating a problem of small sample bias as demonstrated by Banerjee et al. (1986). On the other hand, overlapping data are not a problem if the model specification does not involve any dynamics. Therefore, it would be erroneous to estimate the cointegrating relation using either the Johansen (1988) procedure or the DOLS and

[12] All of these studies tested the effectiveness of arbitrage and speculation in the forward foreign exchange market. Little, if any, equivalent work has been done on the oil futures market.

[13] The condition, $w_{t+1} \sim I(0)$, is less stringent than the rational expectations requirement that w_{t+1} is a white noise process. The latter requires the following conditions to be satisfied: $E(w_{t+1}) = 0$, $E(w_{t+1} w_{t+1+j}) = \sigma_w^2$ for $j = 0$, and $E(w_{t+1}, w_{t+1+j}) = 0$ for $j \neq 0$.

DGLS estimation methods proposed by Stock and Watson (1993).[14] However, estimating the cointegrating relation as a static regression will produce (subject to small sample bias) super consistent estimates irrespective of the conventional econometric problems, provided that the variables are cointegrated. The problem of inefficiency can be tackled by the adjustment procedure proposed by West (1988) which makes the estimated standard errors of the coefficients asymptotically normal.

EMPIRICAL RESULTS

Before testing for cointegration, unit root tests must be carried out on the variables entering eqs. (15) and (16). For this purpose, two tests and four test statistics are used: the Dickey–Fuller (1979) test (DF and ADF), and the Phillips–Ouliaris (1990) test ($\hat{Z}_\alpha$ and $\hat{Z}_t$).[15] The results of these tests are reported in Table II. The results show that the three variables are nonstationary in levels and stationary in first differences, implying that they are integrated of order 1.

Table III reports the results of testing for cointegration and coefficient restrictions on eqs. (15) and (16). The t statistics for various restrictions are based on West's (1988) corrected standard errors which are given in parentheses. Three restrictions are tested for both equations: $\beta_0 = 0$, $\beta_1 = 0$, and $\beta_1 = 1$, and two more restrictions are tested for eq. (15) only: $\beta_2 = 0$ and $\beta_1 + \beta_2 = 1$. The results for eq. (16) show that the null hypothesis of no cointegration is rejected at the 5% level by the five test statistics used for this purpose. This is a necessary

TABLE II
Unit Root Tests

Variable	*DF*	*ADF*	$\hat{Z}_\alpha$	$\hat{Z}_t$
F	−3.36	−2.62	−10.37	−2.37
$\bar{F}$	−2.97	−1.50	−11.54	−2.81
S^e	−2.61	−1.52	−10.30	−2.48
ΔF	−7.86[a]	−3.74[a]	−43.95[a]	−7.84[a]
$\Delta \bar{F}$	−7.62[a]	−3.67[a]	−47.04[a]	−7.08[a]
ΔS^e	−7.57[a]	−4.07[a]	−48.02[a]	−7.87[a]

[a]Significant at the 5% level. All variables are measured in natural logarithms.

[14]The proposition that the Johansen procedure is not appropriate when there is a problem of overlapping data is proved formally in Moore and Cullen (1993).

[15]Critical values for the test statistics are tabulated in MacKinnon (1991), and in Phillips and Ouliaris (1990), respectively.

TABLE III
Cointegration and Coefficient Restrictions Tests

	Eq. (15)	*Eq. (16)*
β_0	0.040	0.108
	(0.087)	(0.078)
β_1	0.925	0.951
	(0.029)	(0.026)
β_2	0.049	
	(0.025)	
R^2	0.978	0.974
$CRDW$	1.37[a]	1.27[a]
DF	−5.83[a]	−5.58[a]
ADF	−4.48[a]	−4.19[a]
$\tilde{Z}_\alpha$	−52.11[a]	−49.46[a]
$\tilde{Z}_t$	−6.08[a]	−5.86[a]
$t(\beta_0 = 0)$	0.46	1.39
$t(\beta_1 = 0)$	31.89[a]	36.57[a]
$t(\beta_2 = 0)$	1.96[a]	
$t(\beta_1 = 1)$	−2.59[a]	−1.88[a]
$t(\beta_1 + \beta_2 = 1)$	−1.65	

[a]Significant at the 5% level. Figures in parentheses are West's corrected standard errors which are used to calculate the adjusted t statistics.

but not a sufficient condition for the arbitrage equation to hold. The sufficient condition is that the restrictions $\beta_0 = 0$ and $\beta_1 = 1$ hold. The restriction $\beta_0 = 0$ is not rejected, the restriction $\beta_1 = 1$ is rejected, and the restriction $\beta_1 = 0$ is rejected. The interpretation of these results is as follows: while arbitrage plays a significant role in determining the futures price, it is not powerful enough to achieve the equilibrium described by the arbitrage equation, i.e., $F = \overline{F}$. This means that there must be another force in operation, and this force is speculation.

The role of speculation is illustrated by the results presented in Table III for eq. (15). Again, the necessary condition is satisfied because all of the test statistics reject the null hypothesis of no cointegration. In this case, however, all of the restrictions hold. While the restriction $\beta_2 = 0$ is rejected, implying a statistically significant role for speculation, the restriction $\beta_1 + \beta_2 = 1$ is not rejected, implying that both speculation and arbitrage determine the futures price. The results also confirm the validity of the assumption concerning the role of hedging.

Finally, Table IV presents the results of another test that confirms the importance of speculation in determining futures prices. A variable deletion test is conducted on S_t^e as it appears in eq. (15). Three test statistics are reported: the Lagrange multiplier (LM) test statistic which is distributed as $\chi^2(1)$; the likelihood ratio (LR) test statistic which

TABLE IV
Variable Deletion of Tests on S_t^e

Test Statistic	*Distribution*	*Value*	*Marginal Significance*
LM	$\chi^2(1)$	4.54[a]	0.033
LR	$\chi^2(1)$	4.70[a]	0.030
F	$F(1, 64)$	4.65[a]	0.035

[a]Significant at the 5% level.

is also distributed as $\chi^2(1)$; and the F test statistic which is derived from the residual sum of squares of the restricted and unrestricted regressions.[16] All of these test statistics reject the null hypothesis $\beta_2 = 0$.

The final point to be mentioned here concerns the relative roles of arbitrage and speculation in determining the futures price. These are measured respectively by the magnitudes of the coefficients on $\overline{F}$ and S^e (i.e., β_1 and β_2). But, while both of these coefficients are statistically significant, the value of β_1 (0.925) is by far greater than the value of β_2 (0.049), implying that, during the period under consideration, arbitrage played by a more important role than speculation in determining the futures price. In other words, the oil market was characterized by a situation of arbitrage dominance as shown by Figure 1 and Figure 2. This result is not surprising because this period is characterized by relatively stable oil prices following the collapse of early 1986 and the loss of OPEC's power in dictating events in the oil market. In the period between the collapse of early 1986 and the Iraqi invasion of Kuwait (the effect of which was only temporary), the oil market was not highly volatile. Moreover, one of the important factors which is conducive to speculation in the oil market, the outcome of OPEC meetings, lost its effectiveness. If speculation has played a greater role before OPEC lost its power, then the change can be represented by the shift in the speculation schedule, as in Figure 1, from S3S3 towards S1S1 and then to S2S2. It can be stated that, during the period under study, the role of speculation is secondary to that of arbitrage.

CONCLUSION

In this article, a model is developed to test the effectiveness of arbitrage and speculation in determining the futures price of crude oil. The model

[16]The restricted and unrestricted regressions are represented by eqs. (16) and (15), respectively.

is specified such that the actual futures price is a function of the arbitrage price and the expected spot price. The arbitrage price, which reflects the role of arbitrage, is derived by adjusting the spot price by a factor accounting for the real and financial cost of carry. The real component of the cost of carry is proxied by the inflation rate, while the financial component is proxied by interest rate. The expected spot price, which reflects the role of speculation, is proxied by the actual spot price prevailing at the maturity of the futures contract. This procedure is based on an expectations formation mechanism similar to, but less stringent than, rational expectations.

The model is tested using the WTI crude spot and futures prices over the period of January, 1986 through December, 1991. The empirical results reveal that speculation plays a role in determining futures prices, but that the role of arbitrage is dominant during the period tested. The dominance of arbitrage over speculation may have been caused by a decline in the power of OPEC which made the oil market less volatile and reduced the uncertainty surrounding the movement of oil prices. Such an environment is less conducive to a big role for speculation in the oil futures market.

There are two possible extensions to this study. First, it would be interesting to test the hypothesis over a less stable period such as 1973–82 to see if the change in the sample period results in the same dominance of arbitrage over speculation. Second, it is possible to extend the model and make it more general by relaxing the assumption of zero convenience yield.

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