A Market-augmented Model for SIMEX Brent Crude Oil Futures Contracts

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Abstract Brent crude oil futures contracts are traded on both the Singapore International Monetary Exchange (SIMEX) and the International Petroleum Exchange (IPE). Through a Mutual Offset System between SIMEX and IPE, Brent crude oil futures contracts can be traded up to nineteen hours each day. The inter-relationship between the two futures contracts, the spot price of Brent crude oil and the risk-free interest rate, suggest the existence of cointegration among the IPE and SIMEX Brent crude oil futures prices, Brent spot prices and the London Inter-bank Offer Rate (LIBOR). Error-correction representations of two standard futures pricing models, namely the Unbiased Expectations and Cost-of-Carry hypotheses, are formulated for SIMEX Brent crude oil futures contracts. These formulations are augmented by including the IPE futures price in the mispricing error. The resulting Augmented Unbiased Expectations Hypothesis (AUEH) and the Augmented Cost-of-Carry (ACOC) models are estimated and tested against each other, and also against the standard Unbiased Expectations and Cost-of-Carry models, using nested and non-nested testing procedures. Forecasting comparisons are also made among the various models and the Autoregressive Integrated Moving Average models fitted to SIMEX Brent crude oil futures prices. Results from the non-nested tests and the forecasting criteria show clearly that the augmented models outperform their standard (non-augmented) counterparts.

1. INTRODUCTION

The growing interest in trading financial and commodity derivatives has led to a globalisation of these markets, extending transactions beyond national boundaries. Mutual Offset Systems (MOS) have developed in recent years between international exchanges that serve traders across different time zones. The first MOS was established in 1984 between the Singapore International Monetary Exchange (SIMEX) and the Chicago Mercantile Exchange. With the development of an MOS between international exchanges, investors are now able to continue trading in a particular futures contract even after one exchange has closed for the day, since the same contract is offered on another international exchange. The SIMEX Brent crude oil futures contract, which is one such example of a futures contracts traded on an MOS operating between SIMEX and the International Petroleum Exchange (IPE), was first established between these two markets in June 1995.

As a result of the MOS, trading of the Brent futures can be traded continuously for up to nineteen hours each day: trading begins at 9.25am on SIMEX and continues until the exchange closes at 5.58pm, after which trading in Brent futures continues when the IPE opens for trading, and eventually closes for the day at 4.15am, Singapore time. In such an arrangement, the settlement price of the Brent futures traded on SIMEX at the end of the trading day is likely to differ from the settlement price of Brent futures traded on the IPE due to the time difference between SIMEX and the IPE. As the futures prices in such contracts are determined in both markets independently, the settlement price at the end of the trading day on the IPE provides price information that may be used to augment existing formulations of SIMEX futures pricing models.

The Unbiased Expectations Hypothesis (UEH) and Cost-of-Carry (COC) model are the standard theoretical models for pricing futures contracts in conventional studies. In a recent study, Sequeira and McAleer (1997) found substantial evidence for the Cost-of-Carry hypothesis in pricing Australian dollar futures contracts traded on the International Monetary Market of the Chicago Mercantile Exchange.

Following a similar approach, UEH and COC models can be formulated for SIMEX Brent futures contracts. In this paper, both the UEH and COC formulations are augmented to include the IPE Brent futures price in the error-correction representation of the two models. These models will be denoted the Augmented Unbiased Expectations Hypothesis (AUEH) and the Augmented Cost-of-Carry (ACOC) model.

In Section 2, the UEH and COC models are presented. Empirical specifications corresponding to the UEH and COC models, and their augmented counterparts, are derived in Section 3. Appropriate hypotheses and tests are discussed in Section 4. Section 5 describes the data to be used in the study, and Section 6 presents the test results of non-stationarity, cointegration and non-nested hypotheses. Estimation results are presented in Section 7, and concluding remarks are given in Section 8.

2. MODELS OF FUTURES PRICES

2.1 Unbiased Expectations Hypothesis

The Unbiased Expectations Hypothesis (UEH) is developed from the Risk Premium hypothesis, based on the analysis in Fama and Farber (1979) and the theoretical model of Stulz (1981). In natural logarithms, the Risk Premium hypothesis is specified as:

(1) $f_{t+k|t} = E_t(s_{t+k}) + \pi_{t+k|t}$

where $f_{t+k|t}$ is the price of a k-period futures contract at time t, $E_t(s_{t+k})$ is the forecast of the future spot price at time $t+k$, conditional on the information set at time t, and $\pi_{t+k|t}$ is the (time varying) expected risk premium from time t to $t+k$. Futures contracts can be sold or bought at each time period in between the time the contract is first listed on the exchange, through to the maturity of that particular contract. Analysis involving one-day ahead forecasts are useful in understanding the behaviour of futures prices in these markets. Setting k=1, equation (1) can be rewritten as:

(2) $f_t = E_t(s_{t+1}) + \pi_t$

where $f_t \equiv f_{t+1|t}$ and $\pi_t \equiv \pi_{t+1|t}$.

Thus, apart from the risk premium, the futures price is unbiased for the spot price.

2.2 Cost-of-Carry Model

The Cost-of-Carry (COC) model uses a no-arbitrage argument by accommodating the carrying costs involved in holding an underlying asset until maturity. For commodity futures contracts, the underlying asset is the commodity itself, and the carrying costs are essentially the net storage costs (that is, storage cost less convenience yield) and the risk-free interest rate. Following the derivation of futures prices given in Amin and Jarrow (1991), the price of a commodity futures contract is given as follows:

(3) $F_{t+k|t} = S_t \dfrac{p^c_{t+k|t}}{p^d_{t+k|t}}\left\{\exp\theta_{t+k|t}\right\}$

where $p^c_{t+k|t} = \exp\left\{-kc_{t+k|t}\right\}$

and $p^d_{t+k|t} = \exp\left\{-kr_{t+k|t}\right\}$.

In equation (3), $c_{t+k|t}$ represents the net carrying costs from time t to $t+k$, $r_{t+k|t}$ represents the k-period interest rate at time t, and $\theta_{t+k|t}$ represents an adjustment term for the marking-to-market feature of futures markets contracts. Substituting the expressions for $p^c_{t+k|t}$ and $p^d_{t+k|t}$ into equation (3) yields the following expression:

(4) $F_{t+k|t} = \dfrac{S_t \exp\left\{-kc_{t+k|t}\right\}\cdot\exp\theta_{t+k|t}}{\exp\left\{-kr_{t+k|t}\right\}}$.

Using the natural logarithms of (4), the Cost-of-Carry model for a commodity futures price is obtained as follows:

(5) $\ln F_{t+k|t} = \ln S_t + kr_{t+k|t} - kc_{t+k|t} + \theta_{t+k|t}$.

Following the convention of setting k=1, and denoting $\ln F_{t+1|t}, \ln S_t, r^d_{t+1|t}, c_{t+1|t}$ and $\theta_{t+1|t}$ by f_t, s_t, r_t, c_t and θ_t, respectively, equation (5) can be written as:

(6) $f_t = s_t + r_t - c_t + \theta_t$.

3.1 FORMULATION OF MODELS AND THEIR AUGMENTED COUNTERPARTS

3.1 Unbiased Expectations Hypothesis and Cost-of-Carry Model

Based on the theoretical models of the Unbiased Expectations and Cost-of-Carry hypotheses, empirical specifications corresponding to the two models can be derived. Accordingly, the UEH model given in equation (2) can be specified as follows:

(7) $f_t = \alpha_0 + \alpha_1 s_{t+1} + \alpha_2 \pi_t + \eta_t$

where f_t is the (logarithmic) price of a one-period ahead futures contract at time t, s_{t+1} is the (logarithmic) spot price at time $t+1$, and π_t is the (logarithmic) one-period ahead time-varying risk premium. Similarly, the empirical form of the Cost-of-Carry model in equation (6) can be rewritten as follows:

(8) $f_t = \beta_0' + \beta_1' s_t + \beta_2' r_t + \beta_3' c_t + \beta_4' \theta_t + v_t$.

In specifications of the UEH and COC models, the risk premium, the net carrying cost, and the adjustment term for the marking-to-market feature are not directly observable. Park and Phillips (1989) have shown that a stationary variable can be omitted from a cointegrating regression without affecting the consistency of the coefficient estimates or the power of the accompanying hypothesis testing procedures. Consequently, if the net carrying cost and the marking-to-market adjustment term are also I(0), the UEH and COC models can be specified without including these three variables. The two models can, therefore, be estimated directly, even when the futures price, spot price, and risk-free rate of interest contain stochastic trends.

Within a cointegration framework, equations (7) and (8) can be rewritten without the net carrying cost, the risk premium and the marking-to-market adjustment term. These assumptions result in the empirical specification for the UEH given in equation (9) and the COC models in equations (10):

(9) $f_t = \alpha_0 + \alpha_1 s_{t+1} + u_t$

(10) $f_t = \beta_0' + \beta_1' s_t + \beta_2' r_t + u_t'$.

To enable a direct comparison to be made of the UEH and COC models, s_t is used in place of s_{t+1} in equation (9) because, within a cointegration framework, time leads or lags do not affect the specification or the statistical outcomes of hypothesis tests. Equation (9) can be rewritten as:

(11) $f_t = \beta_0 + \beta_1 s_t + u_t$.

Following Engle and Granger (1987), if the futures and spot prices are cointegrated, there exists an error-correction representation of the relationship between the two variables. If the SIMEX Brent futures and Brent spot price are cointegrated, the UEH given in equation (11) can be rewritten as an error-correction representation as follows:

(12) $\Delta f_t = b_0^* + b_1^* \Delta f_{t-1} + b_2^* \Delta s_t - a^* (f_{t-1} - \beta_1^* s_{t-1}) + \varepsilon_t^*$.

The error-correction model is specified with one lag of the variables because the analysis involves one-day ahead forecasts. Additional lags of the variables may be included in the error-correction model, as required. The COC model for SIMEX futures prices may be reformulated according to the stationarity and cointegration properties of the SIMEX futures price, the underlying Brent spot price, and the risk-free rate of interest. Accordingly, two interpretable cases for the COC model, corresponding to Cases 1 and 2, are as follows:

(1) all three variables are I(1) and are cointegrated;

(2) the risk-free rate of interest is I(0), and the two price variables are I(1) and are cointegrated;

In case 1, the SIMEX futures price, Brent spot price, and risk-free interest rate are all I(1) and are cointegrated. The error-correction representation for the three variables can be formulated as follows:

(13) $\Delta f_t = b_0 + b_1 \Delta f_{t-1} + b_2 \Delta s_t + b_3 \Delta r_t - a(f_{t-1} - \beta_1 s_{t-1} - \beta_2 r_{t-1}) + \varepsilon_t$.

Case 2 occurs when the risk-free interest rate is I(0), and the SIMEX futures and the Brent spot price are I(1) and are cointegrated. Following the result of Park and Phillips, the I(0) risk-free interest rate can be omitted from the cointegrating regression. In this case, the appropriate error-correction representation is as follows:

(14) $\Delta f_t = b_0' + b_1' \Delta f_{t-1} + b_2' \Delta s_t + b_3' r_t - a'(f_{t-1} - \beta_1' s_{t-1}) + \varepsilon_t'$.

3.2 Augmented UEH and COC Formulations

To derive the augmented forms of the UEH and COC models, the IPE futures price is included in the error-correction formulations of both models. If the IPE futures price series is I(1) and is cointegrated with the SIMEX futures price and Brent spot price, the error-correction representation of the Augmented Unbiased Expectations Hypothesis (AUEH) can be expressed as:

(15) $\Delta f_t = b_0^{**} + b_1^{**} \Delta f_{t-1} + b_2^{**} \Delta s_t + b_3^{**} \Delta i_t - a^{**}(f_{t-1} - \beta_1^{**} s_{t-1} - \beta_2^{**} i_{t-1}) + \varepsilon_t^{**}$.

where Δi_t is the first difference of the (logarithmic) price of a one-period ahead IPE Brent crude oil futures contract at time *t+1*.

The Augmented Cost-of-Carry (ACOC) model for SIMEX futures prices is reformulated according to the stationarity and cointegration properties of the SIMEX futures price, the underlying Brent spot price, the IPE futures price, and the risk-free rate of interest. For the ACOC model, two interpretable cases, corresponding to Cases 1' and 2', are as follows:

(1') all four variables are I(1) and are cointegrated;

(2') the risk-free rate of interest is I(0), and the three price variables are I(1) and are cointegrated;

Case (1') occurs when the SIMEX futures price, the IPE futures price, the Brent spot price and the risk-free rate of interest are all I(1) and are cointegrated. The error-correction representation of the relationship for the four variables can be formulated as follows:

$$(16)\quad \Delta f_t = b_0'' + b_1''\Delta f_{t-1} + b_2''\Delta s_t + b_3''\Delta i_t + b_4''\Delta r_t - a''(f_{t-1} - \beta_1'' s_{t-1} - \beta_2'' i_{t-1} - \beta_3'' r_{t-1}) + \varepsilon_t''.$$

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n case (2'), the risk-free interest rate is I(0), and the SIMEX futures price, IPE futures price and Brent spot price are I(1) and are cointegrated. The result of Park and Phillips is again applied, and the risk-free interest rate may be omitted from the cointegrating regression without affecting the statistical properties of the estimators and tests. The appropriate error-correction representation is as follows:

$$(17)\quad \Delta f_t = b_0''' + b_1'''\Delta f_{t-1} + b_2'''\Delta s_t + b_3'''\Delta i_t + b_6''' r_t - a'''(f_{t-1} - \beta_1''' s_{t-1} - \beta_2''' i_{t-1}) + \varepsilon_t'''.$$

4. FORMULATION OF HYPOTHESES

The UEH and the two COC formulations, Cases 1 and 2, are given as hypotheses H_1 to H_3, while the AUEH and the two ACOC formulations, Cases 1' and 2', are given as hypotheses H_4 to H_6.

Hypothesis H_1

The error-correction representation of the UEH model based on equation (12) is denoted as hypothesis H_1, and is given as follows:

$H_1 : y = Z_1\gamma_1 + \varepsilon_1$, where

$$Z_{1t}' = \left[1, \Delta f_{t-1}, \Delta s_t, \left(f_{t-1} - \beta_1^* s_{t-1}\right)\right]$$

$$\gamma_1' = \left[b_0^* \quad b_1^* \quad b_2^* \quad a^*\right]$$

and $\varepsilon_{1t} = \varepsilon_t^*$,

where Z_{1t}' represents the vector of explanatory variables in the error-correction model, γ_1' is the corresponding vector of coefficients, and ε_{1t} is a stationary white noise process. The UEH formulation will include an error-correction term for the mispricing error, denoted UECM.

Hypothesis H_2

Hypothesis H_2 is based on Case 1, in which all three variables in the COC model are I(1) and are cointegrated. The error-correction representation of the relationship between the three variables is given in equation (13), and this COC hypothesis is given as follows:

$H_2 : y = Z_2\gamma_2 + \varepsilon_2$, where

$$Z_{2t}' = \left[1, \Delta f_{t-1}, \Delta s_t, \Delta r_t, \left(f_{t-1} - \beta_1 s_{t-1} - \beta_2 r_{t-1}\right)\right]$$

$$\gamma_2' = \left[b_0 \quad b_1 \quad b_2 \quad b_3 \quad a\right]$$

and $\varepsilon_{2t} = \varepsilon_t$,

where Z_{2t}' represents the vector of explanatory variables in the error-correction model, γ_2' is the corresponding vector of coefficients, and ε_{2t} is a stationary white noise process. The COC formulation will include an error-correction term for the mispricing error, denoted CECM.

Hypothesis H_3

When the risk-free interest rate is I(0), and the other two I(1) variables in the COC formulation are cointegrated, Case 2 applies. The mispricing error between the SIMEX futures and Brent spot prices in this error-correction representation is denoted C1ECM. The hypothesis H_3 based on equation (14) is as follows:

$H_3 : y = Z_3\gamma_3 + \varepsilon_3$, where

$$Z_{3t}' = \left[1, \Delta f_{t-1}, \Delta s_t, r_t, \left(f_{t-1} - \beta_1' s_{t-1}\right)\right]$$

$$\gamma_3' = \left[b_0' \quad b_1' \quad b_2' \quad b_3' \quad a'\right]$$

and $\varepsilon_{3t} = \varepsilon_t'$,

where Z_{3t}' represents the vector of explanatory variables in the error-correction model, γ_3' is the corresponding vector of coefficients, and ε_{3t} is a stationary white noise process.

Hypothesis H_4

For the AUEH model, the error-correction representation given by equation (15) is given as hypothesis H_4:

$H_4 : y = Z_4\gamma_4 + \varepsilon_4$, where

$$Z_{4t}' = \left[1, \Delta f_{t-1}, \Delta s_t, \Delta i_t, \left(f_{t-1} - \beta_1^{**} s_{t-1} - \beta_2^{**} i_{t-1}\right)\right]$$

$$\gamma_4' = \left[b_0^{**} \quad b_1^{**} \quad b_2^{**} \quad b_3^{**} \quad a^{**}\right]$$

and $\varepsilon_{4t} = \varepsilon_t^{**}$,

where Z_{4t}' represents the vector of explanatory variables in the error-correction model, γ_4' is the corresponding vector of coefficients, and ε_{4t} is a stationary white noise process. The AUEH formulation will include an error-correction term for the mispricing error, denoted AUECM.

Hypothesis H_5

When all four variables are cointegrated in the ACOC model, Case 1' applies. The ACOC formulation will include a mispricing error describing the long-run relationship between the SIMEX futures, IPE futures, Brent spot price and the risk-free interest rate, and is denoted ACECM. The hypothesis for this ACOC formulation, denoted H_5, is based on equation (16) as follows:

$H_5 : y = Z_5\gamma_5 + \varepsilon_5$, where

$$Z_{5t}' = \begin{bmatrix} 1, \Delta f_{t-1}, \Delta s_t, \Delta i_t, \Delta r_t, \\ \left(f_{t-1} - \beta_1'' s_{t-1} - \beta_2'' i_{t-1} - \beta_3'' r_{t-1}\right) \end{bmatrix}$$

$$\gamma_5' = \left[b_0'' \quad b_1'' \quad b_2'' \quad b_3'' \quad b_4'' \quad a''\right]$$

and $\varepsilon_{5t} = \varepsilon_t^{*}$,
where Z'_{5t} represents the vector of explanatory variables in the error-correction model, γ'_5 is the corresponding vector of coefficients, and ε_{5t} is a stationary white noise process.

Hypothesis H_6

When the risk-free interest rate is I(0), and the three I(1) price variables in the ACOC model are cointegrated, Case 2' applies. The error-correction formulation will include a mispricing error for the three price variables, denoted A1CECM. The hypothesis for this ACOC representation, denoted H_6, is based on equation (17), and is given as follows:

$H_6 : y = Z_6\gamma_6 + \varepsilon_6$, where

$Z'_{6t} = [1, \Delta f_{t-1}, \Delta s_t, \Delta i_t, r_t, (f_{t-1} - \beta_1^{**} s_{t-1} - \beta_2^{**} i_{t-1})]$

$\gamma'_6 = [b_0^{**} \;\; b_1^{**} \;\; b_2^{**} \;\; b_3^{**} \;\; b_4^{**} \;\; a^{**}]$

and $\varepsilon_{6t} = \varepsilon_t^{**}$,

where Z'_{6t} represents the vector of explanatory variables in the error-correction model, γ'_6 is the corresponding vector of coefficients, and ε_{6t} is a stationary white noise process.

5. DATA

Brent crude oil futures contracts traded on SIMEX are used in the empirical analysis. Price data on the IPE Brent crude oil futures price, Brent spot price, and data on the risk-free interest rate (using the London Inter-bank Offer Rate, LIBOR), are obtained from Bridge Information Systems. SIMEX and IPE futures, and Brent spot prices are in natural logarithms, while the risk-free interest rate is expressed in levels.

Futures price data are extracted from seventeen monthly contracts covering the period July 1995 to December 1996. The settlement price for the nearest contract was used as the futures price series, with some adjustment for the crossover when the contract is near to maturity. Following this procedure, a total of 388 observations on SIMEX and IPE futures prices are obtained.

6. NON-STATIONARITY AND COINTEGRATION TESTS

6.1 Non-stationarity Tests

Four sets of variables, comprising data on SIMEX futures price, IPE futures price, Brent spot price, and the risk-free interest rate, are tested for unit roots using the augmented Dickey-Fuller (ADF) test The ADF statistics obtained are compared with the simulated critical values given in MacKinnon (1991).

Results of the ADF test for all four variables and their first differences are presented in Table 1. A Newey-West covariance matrix, denoted NW, is used to calculate several of the unit root tests when Lagrange Multiplier diagnostics for the presence of serial correlation and heteroskedasticity are found to be significant. The results suggest the presence of a unit root in all four variables. Tests applied to the first differences of the variables strongly reject the null hypothesis of a unit root, which implies that all four variables are integrated of order one, I(1).

6.2 Cointegration Tests

Johansen's (1991) maximal eigenvalue and trace tests are applied to two variables (f_t, s_t) in the UEH model, three variables (f_t, s_t, r_t) in the COC model, three variables (f_t, s_t, i_t) in the AUEH model, and four variables (f_t, s_t, r_t, i_t) in the ACOC model, to test for cointegrating relationships among the variables in each of the four models. On the basis of the test results, which are consistent for the two tests in all cases, the number of cointegrating relations between the variables can be established, as in Table 2.

One cointegrating vector is found to be present between the variables in the UEH model describing the long-run relationship between the SIMEX futures price and the Brent spot price. An error-correction representation of the relationship between the two variables includes an error-correction term, denoted UECM. Similarly, one cointegrating vector is obtained among the SIMEX futures price, the Brent spot price, and the risk-free interest rate in the COC relationship, for which the error-correction term is denoted CECM.

For the AUEH model, two cointegrating vectors are obtained. The two error-correction terms are denoted AUECM1 and AUECM2, describing the long-run relationship between the SIMEX futures price, IPE futures price and the Brent spot price. For the ACOC model, the tests also suggest the presence of two cointegrating vectors, depicting the long-run relationship among the three prices and the risk-free rate of interest. The error-correction terms in the ACOC model are denoted ACECM1 and ACECM2.

6.3 Non-nested Tests

From the results of the tests of unit roots conducted in Section 6.1, all four variables are I(1). Cases 2 and 2' are eliminated as appropriate formulations for the COC and ACOC models, respectively, as these formulations are based on the risk-free interest rate being I(0), which is rejected by the data.

The two augmented models, namely, the ACOC and the AUEH models, are tested against each other and also against their non-augmented counterparts: ACOC(H_5) is tested against AUEH (H_4); ACOC(H_5) is tested against COC(H_2); and AUEH(H_4) is tested against UEH(H_1). As each of the error-correction terms in the four models are linearly independent, these comparisons require appropriate non-nested testing procedures.

Six non-nested tests and two information criteria are reported in Table 3. For ACOC against AUEH, the tests do not reject either the ACOC or the AUEH model, with both AIC and SBIC preferring AUEH over ACOC; the non-nested tests reject COC, but do not reject ACOC, with both AIC and SBIC preferring ACOC to COC; and the non-nested tests reject UEH, but do not reject AUEH, with both AIC and SBIC favouring AUEH over UEH.

The tests provide substantial support for the augmented models as preferred choices for the pricing of SIMEX Brent futures over their non-augmented counterparts. Based on these results, there is no clear preference between the ACOC and the AUEH, although both AIC and SBIC favour the AUEH model over the ACOC model.

7. ESTIMATION

Table 4 presents the results of the four models estimated for SIMEX futures prices. Lagged first differences of f_t, s_t, r_t, and i_t are included in the ACOC model, and lagged first differences of f_t, s_t and i_t are included in the AUEH model to accommodate serial correlation in the model.

The Lagrange Multiplier test for heteroskedasticity (LM(H)) is significant in the ACOC and AUEH models, and the RESET test for functional form misspecification is also significant in these two augmented models. For these reasons, a Newey-West covariance matrix is used for purposes of inference in the ACOC and AUEH models. Although the Lagrange Multiplier test for normality (LM(N)) is significant in all four models, this is a feature which is evident in most models of futures prices with skewed distributions.

Several autoregressive (AR), moving average (MA), and autoregressive moving average (ARMA) models are estimated for the SIMEX futures prices to establish whether the data could be effectively described by any of these models.

Various AR and MA models are fitted to determine whether the data could be described by any of these processes. Several ARMA models are also fitted to the dataset. Some of the models registered low t-statistics of the estimated parameters and are subsequently rejected. The remaining ARMA models are compared using AIC and SBIC, leading to the selection of the ARMA(1,1) model. As the Lagrange Multiplier test for autoregressive conditional heteroskedasticity significant in the ARMA(1,1) model, an ARMA-GARCH(1,1) is estimated as follows:

$$(19) \qquad \underset{(0.00)}{(1-0.9L)}\Delta f_t = \underset{(0.00)}{(1+0.85L)}\hat{h}_t$$

$$\text{where} \quad \hat{h}_t = \underset{(0.18)}{0.00} + \underset{(0.00)}{0.15}\hat{h}_{t-1} + \underset{(0.00)}{0.85}\hat{\varepsilon}^2_{t-1}$$

DW = 1.997, Log-likelihood = 1023.07, AIC = -7.83.

Five different models, namely, the UEH, COC, AUEH, ACOC and ARMA-GARCH, are estimated, and their performances are evaluated on the basis of their relative forecasting ability. Root mean squared error (RMSE) and the mean absolute error (MAE) are used to evaluate their relative forecasting performance.

Table 5 presents the results obtained for the five models. The AUEH model outperforms the others on the basis of RMSE, while the ACOC performs best on the basis of MAE. Moreover, the augmented models perform very well against their non-augmented counterparts, which suggests that models incorporating price information from another market operating in an MOS perform better on the basis of both RMSE and MAE. The ARMA-GARCH model performs the worst in terms of both RMSE and MAE.

8. CONCLUSION

Since the development of Mutual Offset Systems between international markets, the first such system having been established between SIMEX and the Chicago Mercantile Exchange in 1984, it has become increasingly important to recognize the price linkages between markets involved in such an arrangement.

Models of futures pricing that incorporate such linkages into the information set can be expected to perform better than existing models. The empirical results obtained in this paper strongly support this proposition in the case of SIMEX Brent crude oil futures contracts. On the basis of MAE and RMSE, the augmented models of the Unbiased Expectations Hypothesis and the Cost-of-Carry model strongly outperform their non-augmented counterparts, as well as an ARIMA time series model.

Such empirical results highlight the importance of estimating market-augmented models for SIMEX Brent crude oil futures prices, and underscores the need to include price information from another market in formulating futures pricing models for both financial and commodity futures prices operating in a Mutual Offset System.

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Table 1: Unit root tests

Test Procedure	SIMEX Futures	Brent Spot	IPE Futures	Rates
Levels:				
Lag length	0	9	9	1
Covariance matrix formula	NW	NW	NW	NW
ADF statistic	-3.27	-2.68	-2.66	-1.37
Critical value	-3.42	-3.42	-3.42	-3.42
First differences:				
Lag length	0	9	9	1
Covariance matrix formula	NW	NW	NW	NW
ADF statistic	-3.27	-2.68	-2.66	-1.37
Critical value	-3.42	-3.42	-3.42	-3.42

Notes:
A deterministic trend is included in testing for a unit rootin the levels of the variables, but not in first differences. NW denotes the Newey-West covariance matrix formula. Unless stated otherwise, the OLS covariance matrix formula is used in the calculation of the test statistics.

Table 2: Cointegration tests

Test Statistics	Number of cointegrating vectors			
	UEH	COC	AUEH	ACOC
Maximal Eigenvalue	1	1	2	2
Trace	1	1	2	2

Table 3: Non-nested tests

Tests	ACOC vs AUEH	ACOC vs COC	AUEH vs UEH
N	-0.770 (0.441)	-0.639 (0.523)	0.257 (0.797)
NT	-0.644 (0.519)	-0.618 (0.537)	0.251 (0.801)
W	-0.643 (0.520)	-0.618 (0.537)	0.251 (0.801)
J	0.713 (0.476)	0.628 (0.530)	-0.254 (0.800)
JA	0.714 (0.475)	0.628 (0.530)	-0.254 (0.800)
F	0.303 (0.739)	0.395 (0.530)	0.064 (0.800)
Tests	**AUEH vs ACOC**	**COC vs ACOC**	**UEH vs AUEH**
N	-1.883 (0.060)	-321.5* (0.000)	-1919.1* (0.000)
NT	-0.903 (0.366)	-56.0* (0.000)	-63.7* (0.000)
W	-0.899 (0.368)	-44.5* (0.000)	-50.7* (0.000)
J	1.684 (0.092)	15.5* (0.000)	15.4* (0.000)
JA	1.297 (0.195)	-0.204 (0.839)	-0.249 (0.804)
F	0.752 (0.557)	39.6* (0.000)	47.1* (0.000)
AIC	Favours AUEH	Favours ACOC	Favours AUEH
SBIC	Favours AUEH	Favours ACOC	Favours AUEH

Notes:
a. The figures in parentheses denote probability values;
* denotes significance at the 5% level.
b. The non-nested tests are as follows:
N: Cox test of Pesaran (1974).
NT: Adjusted Cox test of Godfrey and Pesaran (1983).
W: Wald-type test of Godfrey and Pesaran (1983).
J: Davidson and MacKinnon (1981).
JA: Fisher and McAleer (1981).
F: Pesaran (1974), Deaton (1982), Dastoor (1983), Gourieroux et al. (1983), Mizon and Richard (1986), and McAleer and Pesaran (1986).
AIC: Akaike Information Criterion (AIC).
SBIC: Schwarz's Bayesian Information Criterion (SBIC).

Table 4: Estimation results

Variables	Models			
	UEH	COC	AUEH	ACOC
Constant	-0.000 (0.557)	-0.085* (0.000)	0.004* (0.000)	-0.055* (0.000)
Δf_{t-1}	-0.115* (0.001)	0.114* (0.001)	0.014 (0.837)	-0.018 (0.792)
Δs_t	0.719* (0.000)	0.729* (0.000)	0.256* (0.007)	0.260* (0.008)
Δs_{t-1}	-	-	-0.121 (0.278)	-0.127 (0.254)
Δi_t	-	-	0.160* (0.000)	0.163* (0.000)
Δi_{t-1}	-	-	0.277* (0.000)	0.285* (0.000)
Δr_t	-	0.006 (0.757)	-	0.012 (0.245)
Δr_{t-1}	-	-	-	-0.014 (0.159)
ACECM1	-	-	-	-0.094* (0.000)
ACECM2	-	-	-	0.033* (0.001)
AUECM1	-	-	-0.094* (0.000)	-
AUECM2	-	-	0.0322* (0.003)	-
CECM	-	-0.148* (0.000)	-	-
UECM	-0.139* (0.000)	-	-	-
Diagnostics	**Models**			
	UEH	COC	AUEH	ACOC
DW	2.09	2.083	1.976	1.983
LM(S)	2.30 (0.130)	1.99 (0.158)	0.56 (0.453)	0.25 (0.620)
RESET	0.03 (0.867)	0.12 (0.729)	6.23* (0.013)	4.91* (0.027)
LM(N)	26630* (0.000)	28030* (0.000)	14057* (0.000)	13877* (0.000)
LM(H)	0.14 (0.710)	0.17 (0.677)	18.00* (0.000)	18.47* (0.000)

Notes:
a. DW denotes the Durbin-Watson statistic, LM(S) is the Lagrange Multiplier test for serial correlation, RESET is Ramsey's test for functional form mis-specification, LM(N) is the Lagrange Multiplier test for normality, and LM(H) is the Lagrange Multiplier test for heteroskedasticity.
b. Figures in parentheses are p-values; * denotes significance at the 5% level.

Table 5: Forecasting performance of various models

Models	RMSE	MAE
ACOC	0.00825	0.00686
AUEH	0.00807	0.00688
COC	0.01263	0.00930
UEH	0.02508	0.00923
ARMA-GARCH	0.03062	0.02444

Notes:
ACOC: Augmented Cost-of-Carry model.
AUEH: Augmented Unbiased Expectations Hypothesis model.
COC: Cost-of-Carry model.
UEH: Unbiased Expectations Hypothesis model.