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Does knowledge of the cost of carry model improve commodity futures price forecasting ability?

A case study using the London Metal Exchange lead contract

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Abstract

The use of futures prices to predict commodity cash prices is important both to practitioners and researchers yet the literature provides conflicting results on the ability of futures prices to predict cash prices. Brenner and Kroner [Journal of Financial and Quantitative Analysis 30 (1995) 23] argue that if the cost of carry model applies to commodity futures pricing then current futures prices may not accurately predict subsequent cash prices. Inventory, cash price return variance, cash price return first order auto-correlation and interest rates are used to proxy carrying costs in a test of the ability of commodity futures prices to predict cash prices. Various predictive models relating futures price to cash price are described, including univariate and multivariate error correction models. London Metal Exchange (LME) lead cash prices, lead futures prices, lead inventory and UK treasury bill rates are collected over the period 1964 to 1995. Analysis of this data confirms the importance of the cost of carry model elements as well as futures price in forecasting cash prices.

Keywords: Error correction model; Cost of carry model; Forecasting

1. Introduction

The tests of the relationship between futures price and expected cash price are generally couched in terms of market efficiency. Evidence of bias in the relationship between current futures price and expected cash price is often argued to be evidence of an inefficient market. For example, Chowdhury (1991), Crowder and Hamed (1993), Krehbiel and Adkins (1993), MacDonald and Taylor (1988a) reject cointegration between the cash and futures price. This immediately calls into question the use of futures price to forecast cash price, an important question for both practitioners and for researchers. Brenner and Kroner (1995) argue that this result may not indicate inefficiency because carrying costs could explain the difference between futures price and subsequent cash price. If one or more of the carrying cost

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components are themselves non-stationary then a cointegrating relationship between the cash price and the futures price may not exist. For example, a cointegrating relationship may exist between the components that make up the cost of carry relationship (futures price, cash price and carrying costs/benefits).

Empirical tests of the ability of LME commodity futures prices to predict subsequent cash prices are inconclusive (Chowdhury, 1991; Goss, 1981, 1983; Hsieh & Kulatilaka, 1982; MacDonald & Taylor, 1988a,b, 1989; Moore & Cullen, 1995; Sephton & Cochrane, 1990, 1991). Similarly, the results for a range of commodity and financial futures contracts traded on markets other than the LME provide inconclusive results (Cooper, 1993; Crowder & Hamed, 1993; Krehbiel & Adkins, 1993; Moore, 1994). Explanations for the inconclusive results include differences in statistical techniques (Brenner & Kroner, 1995) and the choice of time periods. The position taken in this paper is consistent with Brenner and Kroner (1995) who argue that carrying cost effects may explain the variation in the level of predictive ability observed for commodity futures prices.

This paper focuses on the cost of carry elements in prediction of cash price. While the following section introduces possible prediction models, Section 3 describes the data used in analysis. Section 4 reports the results of statistical tests, Section 5 compares predictive ability of the models and conclusions follow in Section 6.

2. Futures price and expected cash price

Tests of the ability of futures price to predict cash price take a number of forms. One approach is to regress cash price change on lagged futures price change. Another approach involves regression of cash price change on the lagged difference between futures price and cash price. Although these approaches are common in the literature, it could be argued that they ignore key components in pricing commodity futures contracts, namely carrying costs. There may also be marking to market effects but the impact of marking to market is not included due to the perception that these effects are likely to be economically small (Benninga & Protopapadakis, 1994; Cornell & Reinganum, 1981; French, 1983; Pindyck, 1993).

The simplest model testing the ability of futures price to predict subsequent cash price involves regression of the change in cash price on the lagged futures price change

$$DP_t = a_0 + a_1 DF_{t|t-1} + e_t \tag{1}$$

where D is the change in the variable, P_t is the natural log of the cash price at time t, $F_{t|t-1}$ is the natural log of the futures price observed at time $t-1$ for a contract maturing at time t, the a_i are estimated parameters and e_t is a residual term. The second model involves regression of cash price change on the lagged difference between the futures price and the cash price and takes the form:

$$DP_t = b_0 + b_1(F_{t|t-1} - P_{t-1}) + e_t \tag{2}$$

where the b_i are estimated parameters. Given the cost of carry model, Brenner and Kroner (1995) suggest a more complex form

$$\begin{aligned} DP_t = c_0 &+ c_1 DF_{t|t-1} + c_2 DC_{t|t-1} \\ &+ c_3(P_{t-1} - F_{t-1|t-2} + C_{t-1|t-2})e_t \end{aligned} \tag{3}$$

where $C_{t|t-1}$ is the carrying cost for the period $t-1$ to t assumed known at time $t-1$ and the c_i are estimated parameters. With some rearrangement, the standard ECM format is obtained from Eq. (3)

$$\begin{aligned} DP_t = d_0 &+ d_1 DF_{t|t-1} + d_2 DP_{t-1} \\ &+ d_3 DC_{t|t-1+} d_4 ECT_{t-2}) + e_t \end{aligned} \tag{4}$$

where $ECT_{t-2} = (P_{t-2} - F_{t-1|t-2} + C_{t-1|t-2})$ and the d_i are estimated parameters. Thus a test of the cost of carry model, using a single equation error correction model and assuming futures price and carrying cost are weakly exogenous, also provides an alternative test of the Brenner and Kroner (1995) model.

The importance of convenience yields, as a part of carrying costs, to futures pricing is identified in Bessembinder, Coughenour, Seguin and Smoller (1995), Brennan (1958), Gibson and Schwartz (1990), Heinkel, Howe and Hughes (1990), Milonas and Thomadakis (1997a,b), Schwartz (1997), Weymar (1966) and Working (1949). Often a simple stochastic process exhibiting mean reversion is used to model convenience yields but if carrying costs are to be modelled it would be useful to draw upon a more complete model which explains the existence of convenience yield effects.

Brennan (1958) identifies the importance of inventories in explaining the impact of convenience yield on the spread between futures price and cash price. Wright and Williams (1989) also highlight the impact of stock levels on the difference between futures price and cash price, though they focus on the impact of geographically dispersed storage and the effect of localised stockouts. Both highlight the variation in the impact of inventory on cash and futures prices.

Heinkel et al. (1990) and Milonas and Thomadakis (1997a,b) derive option-based models to explain the convenience yield effect. Although similar results are obtained, there is some variation in the underlying models and suggested explanatory variables. Heinkel et al. (1990) focus on price-taking firms. The convenience yield impact is observed when high demand occurs at some intermediate period prior to futures contract maturity. Given excess demand at the intermediate period, if initial inventories are low, marginal production costs are high and/or demand correlation is negative, then a convenience yield (cash price exceeding futures price) may be observed in the intermediate period. The combination of low inventories and costly production may be sufficient to drive up the intermediate period price with negative correlation in the cash price resulting in a futures price that is set lower than the current cash price. Only those who hold inventory will benefit from selling in this intermediate market while those holding futures contracts will have nothing to sell in the high priced intermediate market. Thus the convenience yield is decreasing in current inventory levels, increasing in marginal costs of production and decreasing in commodity price auto-correlation. Milonas and Thomadakis (1997a,b) also model convenience yields in an option framework, explaining convenience yields in terms of stock levels and specifically identifying the impact of stochastic exercise price and cash price return volatility.

Due to data limitations in the present study, the cash price return first order auto-correlation is chosen to capture the impact of stochastic exercise price (Heinkel et al., 1990). A linear model is chosen for analysis with the convenience yield estimated using a linear function of inventory, cash price return volatility and cash price return first order auto-correlation. The carrying cost function is now written as:

$$C_{t|t-1} = r_{t|t-1} + f_0 + f_1 I_{t-1} + f_2 \sigma_{t-1} + f_3 \rho(1)_{t-1}$$

where the carrying costs ($C_{t|t-1}$) include the impact of interest rates ($r_{t|t-1}$) and the convenience yield which is modelled as a function of the natural log of inventory (I_{t-1}), the natural log of cash price return standard deviation estimated using the previous 20 daily returns (σ_{t-1}) and the cash price return first order auto-correlation coefficient using the previous 20 daily returns ($\rho(1)_{t-1}$). The f_i are estimated parameters. With addition of carrying costs, the cost of carry model can be restated in the form:

$$F_{t|t-1} = P_{t-1} + r_{t|t-1} + f_0 + f_1 I_{t-1} + f_2 \sigma_{t-1} + f_3 \rho(1)_{t-1}. \quad (5)$$

This equation suggests the existence of a long run relationship between the futures price, cash price, interest rate, and convenience yield where the convenience yield is modelled using inventory, cash price return volatility and cash price return first order auto-correlation. Given Eqs. (3) and (5), the Brenner and Kroner (1995) error correction model can be written as:

$$DP_t = g_0 + g_1 DF_{t|t-1} + g_2 Dr_{t|t-1} + g_3 DI_{t-1} + g_4 D\sigma_{t-1} + g_5 D\rho(1)_{t-1} + g_6 ECT_{t-2} + e_t. \quad (6)$$

The error correction term, ECT_{t-2} is the residual, e_{t-1}, from the regression:

$$P_{t-1} = h_0 + h_1 F_{t-1|t-2} + h_1 r_{t-1|t-2} + h_2 I_{t-2} + h_3 \sigma_{t-2} + h_4 \rho(1)_{t-2} + e_{t-1} \quad (7)$$

with g_i and h_i as estimated parameters. Rearranging Eq. (6) provides the more traditional form of the error correction model

$$DP_t = i_0 + i_1 DF_{t|t-1} + i_2 DP_{t|t-1} + i_3 Dr_{t|t-1} + i_4 DI_{t-1} + i_5 D\sigma_{t-1} + i_6 D\rho(1)_{t-1} + i_7 ECT^*_{t-2} + e_t \quad (8)$$

where the error correction term, ECT^*_{t-2} or cost of carry pricing discrepancy, is the residual, e_{t-2}, from the regression:

$$P_{t-2} = j_0 + j_1 F_{t-1|t-2} + j_2 r_{t-1|t-2} + j_3 I_{t-2} + j_4 \sigma_{t-2} + j_5 \rho(1)_{t-2} + e_{t-2}. \quad (9)$$

The i_i and j_i are estimated parameters. Single equation models impose substantial restrictions on the data and so to assess the accuracy of these restrictions a vector error correction model is proposed. This approach caters for the possibility of more complex interactions between the variables as well as allowing for the possibility of both long and short run effects. The initial model is a vector auto-regression in levels with N lagged terms

$$X_t = \sum_{i=1}^{N} K_i X_{t-i} + L + E_t \quad (10)$$

where X_t is a vector of variables, K_i are parameter matrices for the vector auto-regression, L is a vector of constants and E is a vector of residual terms. The inclusion of a constant in the VAR is dependent on the underlying data. Differencing the variables and including a constant term in the vector, X_{t-N}, denoted by X^*_{t-N}, gives the vector error correction model:

$$DX_t = \sum_{i=1}^{N-1} M_i DX_{t-i} + M_N X^*_{t-N} + L + E_t, \quad (11)$$

where $M_N = (K_1 - K_2 - \cdots - K_N - 1)$ is defined equal to the product of the cointegrating vector, B, and the speed of adjustment vector, S, or $M_N = SB'$. The rank of this matrix determines the number of cointegrating vectors. Thus if there is one cointegrating vector, rewriting the error correction term as $ECT^*_{t-N} = B'X^*_{t-N}$ in Eq. (11) gives:

$$DX_t = \sum_{i=1}^{N-1} M_i DX_{t-i} + S'ECT^*_{t-N} + L + E_t. \quad (12)$$

The error correction term (ECT^*_{t-N}) appearing in Eq. (12) consists of the residuals, e_t, from the regression based on Eq. (9). More than one cointegrating vector may exist and methods such as that of Johansen (1988) provide estimates of the cointegrating vectors in the situation where more than one cointegrating vector exists.

3. Data

The LME lead contract is chosen for analysis because of the stability of the deliverable asset over the study period (Sephton & Cochrane, 1991). This is important when dealing with long time series because changes in the grade and acceptable form of the deliverable commodity can have a substantial impact on both pricing and the time series behaviour of prices. Further, the LME provides the opportunity to observe both cash and futures contracts traded at the same time and in the same market. Access to LME lead inventory statistics is also important because LME approved lead can only be delivered under the cash and futures contracts. Thus the cash and futures price will be directly related to the available levels of LME approved lead. It is for this reason that LME lead inventory is preferred to broader definitions that may include less refined metal.

Quarterly observations of futures price, cash price, interest rates and inventory are obtained for analysis of the lead contract over the period December 1964 to June 1995. Unofficial (most trading occurs during the two open outcry 'floor trading' sessions, the midday session and the afternoon session, and these sessions are run each day on the LME trading floor; the midday session provides the official prices and the afternoon session provides the unofficial prices) lead futures prices and cash prices, expressed in GBP, are obtained from the Metal Bulletin for the period up to 1988 and the remainder of the sample is obtained from Datastream. (A filter rule is applied in preliminary analysis of the time series such that all price changes greater than four standard deviations from the mean are checked against the Metal Bulletin prices and where inconsistent the Metal Bulletin price is used.) Futures prices are quoted 3 months to maturity each day and so the time to maturity does not vary from day to day. As physical delivery occurs on both cash and futures contracts, an extensive network of warehouses exists to accept commodities delivered under the contracts. The aggregate inventory (tonnes) held in LME approved warehouses is reported at least weekly throughout the period 1964 to 1995. This aggregate measure provides an indication of the inventory for the specific grades of lead deliverable under LME cash or futures contracts at the end of the last week in the quarter and is obtained from both the LME and the Metal Bulletin. The UK Treasury bill 3-month mid-rate is chosen to proxy for the risk free rate. These rates are obtained from *The Times* newspaper for the period 1964 to 1975 and from Datastream for the period 1975 to 1995. (There are no UK Treasury bill observations available in *The Times* over the periods September 1967 to October 1967 and October 1970 to March 1971. An approximation based on the 2 to 3 month bank bill rate reported in the *Financial Times* is used to proxy for the risk free rate during these periods though there is little variation in these rates evident over the two periods. The spread on the observation immediately preceding the gap and the spread on the observation immediately subsequent to the gap are calculated and the two spreads are apportioned over the missing rate period. The bank bill rates are then adjusted for the spread to provide an approximation of the UK Treasury bill yield over these two short periods.)

Descriptive statistics for the quarterly observations are reported in Table 1. Cash and futures prices average 272.88 GBP and 273.66 GBP, respectively, with a graph of the prices provided in Fig. 1. Fig. 2 provides a graph of the 3-month UK Treasury bill rate. The average rate was 9.27% per annum over the period. Inventory averaged 69,507 tonnes over the period though it is evident that maximum inventory levels have increased over the period. There are also several periods where relatively low levels of inventory are observed (Fig. 3). Cash price return standard deviation and first order auto-correlation are reported in Figs. 4 and 5, respectively. Both standard deviation and first order auto-correlation coefficients are based on returns estimated for the 20 trading days prior to the date of the quarterly observation. The average annual standard deviation of cash price return is ~19.5% ($1.56\times 250/20$) and the average first order auto-correlation coefficient is -0.0431.

Table 1
Descriptive statistics for levels

	Mean	S.D.	Excess skewness	Kurtosis
UK treasury bill 3-month interest rates				
Yield	9.27	3.03	0.34	−0.83
C.C.R.	0.02	0.01	0.33	−0.84
Inventory				
Tons	69,507	83,636	2.06*	3.72*
Natural log	10.54	1.14	−0.02	−0.53
Cash price				
GBP	272.88	126.21	0.19	−0.49
Natural log	5.48	0.55	−0.56*	−0.95*
3-month futures price				
GBP	273.66	124.29	0.04	−0.71
Natural log	5.48	0.55	−0.62*	−0.97*
Cash price return standard deviation per day				
S.D.	0.0156	0.0089	2.54*	10.72*
Natural log	−4.29	0.51	0.01	0.58
Cash price return first order auto-correlation coefficient				
Coefficient	−0.0431	0.2131	0.03	0.11

*Statistically significant at the 5% level of significance. Total sample consists of quarterly observations with $N=123$. The UK Treasury bill yields are quoted as yields per annum and 3-month continuously compounding rate of return (C.C.R.). Interest rates are obtained from *The Times*, *Financial Times* and Datastream. The inventory level is the number of tonnes and the natural logarithm of the number of tonnes of LME approved stock held in LME approved warehouses. Three-month futures prices and cash prices and inventory are obtained from the LME and the Metal Bulletin. The cash price standard deviation and first order auto-correlation are calculated using the 20 prior daily cash price return observations.

Auto-correlation coefficients are reported in Table 2 for each of the variables. Persistence is evident in the cash price, futures price, interest rate and inventories. There is some auto-correlation evident in the cash price return standard deviation time series though the first order auto-correlation coefficient time series shows no evidence of statistically significant auto-correlation with Ljung–Box Q-statistics of 1.99 at four lags and 4.75 at eight lags.

4. Statistical tests

Augmented Dickey–Fuller unit root tests ($Z(t_a)$), including both intercept and trend, are reported in Table 3. These tests were also conducted with adjustment for seasonal effects but as the results were essentially unchanged they are not reported here. Similarly, the non-parametric Phillips and Perron 't-test' ($Z(t_a)$) was also run, though not reported, as the results from this test are also consistent with the augmented Dickey–Fuller test reported here. (Characteristics of both of the tests are reported in Banerjee, Dolado, Galbraith and Hendry (1993).) In Heaney (1998) the unit root tests for the period 1976–1995 suggest that LME cash and futures prices were highly persistent though stationary. Extension of the study period to 1964–1995 results in failure to reject the null of unit root. The existence of one unit root in the

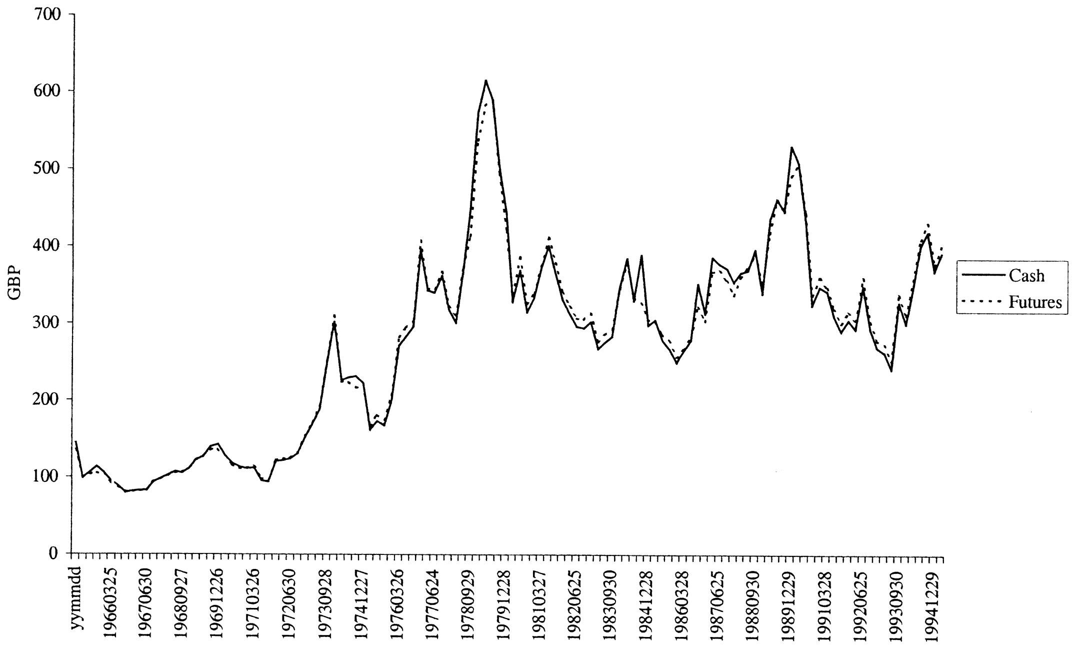

Fig. 1. Lead futures and cash prices. Cash and futures are quarterly observations of the LME cash (prompt) lead price and the LME futures price over the period 25 December 1964 to 29 June 1995 inclusive. The prices are quoted in terms of Great Britain pounds (GBP) per tonne.

Fig. 2. Interest rates are quarterly observations of the Treasury bill 3-month mid-rate over the period 25 December 1964 to 29 June 1995 inclusive.

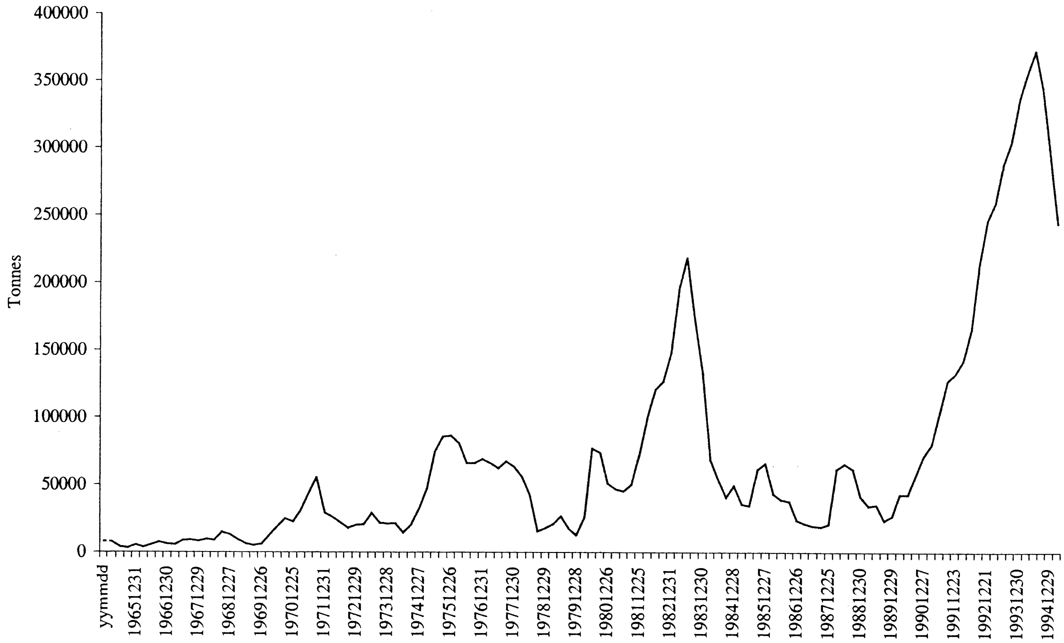

Fig. 3. Lead inventory is the quarterly observations of the LME inventory of lead held in LME warehouses over the period 25 December 1964 to 29 June 1995 inclusive.

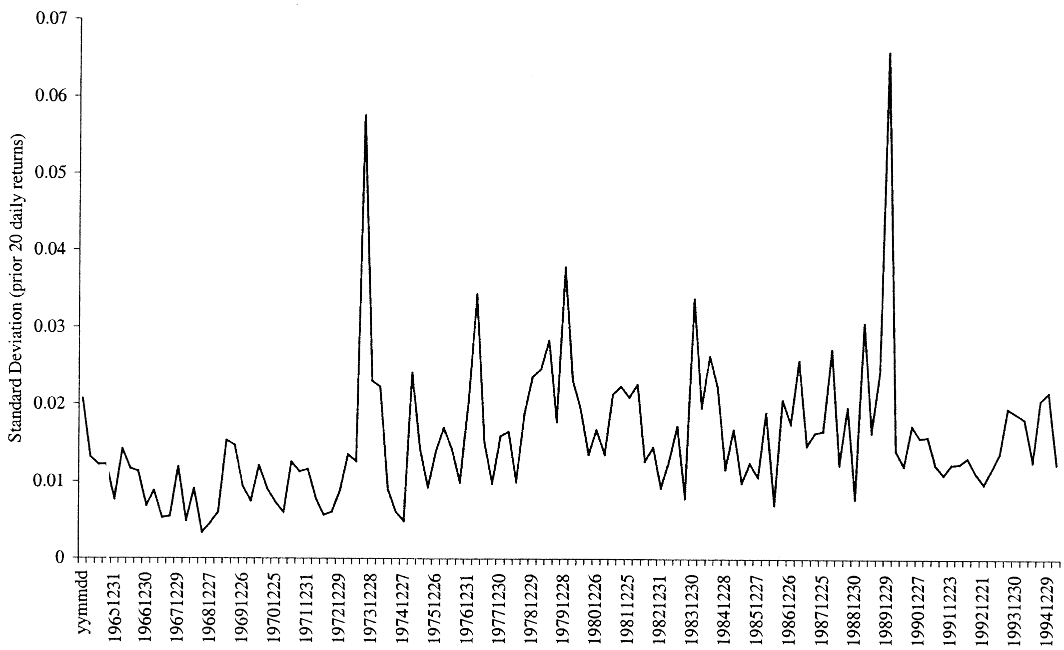

Fig. 4. Standard deviation of the natural log of lead price changes based on the previous 20 daily price change observations taken at quarterly intervals over the period 25 December 1964 to 29 June 1995 inclusive.

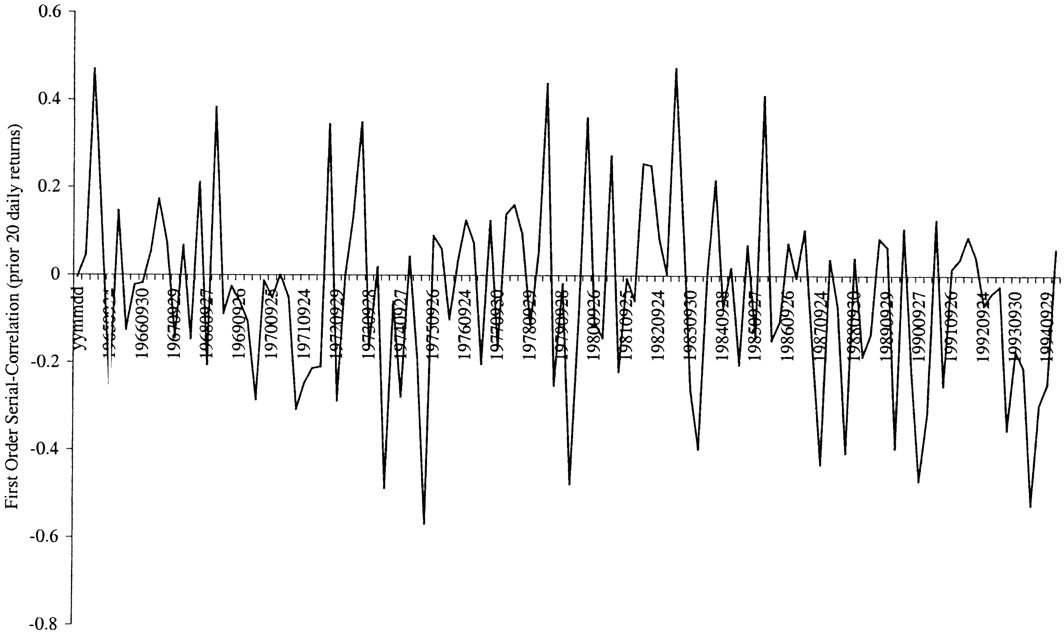

Fig. 5. First order serial-correlation coefficient of the natural log of lead price changes based on the previous 20 daily price change observations taken at quarterly intervals over the period 25 December 1964 to 29 June 1995 inclusive.

futures and cash price time series is also observed in Chowdhury (1991), Franses and Kofman (1991), Krehbiel and Adkins (1993), MacDonald and Taylor (1988b) and Moore and Cullen (1995). Consistent with Hall, Anderson and Granger (1992), MacDonald and Murphy (1989) and Shea (1992), unit root tests cannot reject the null of one unit root in the interest rate time series. Further, the null of unit root cannot be rejected for inventories over the study period. Both the cash price return standard deviation estimates and the cash price return first order auto-correlation coefficient estimates are stationary.

The results of regressions based on Eqs. (1) and (2) are reported in Table 4, panel A and panel B. There are two data sets used. The first data set is for the full period, 1964 to 1995, and the second data set is for the period subsequent to 1975. These regressions offer a base case for comparison as they replicate the early tests of the ability of futures price to predict cash price. These models make no allowance for the possibility of carrying costs.

The regression between lagged futures price change and current cash price change is reported in panel A. The intercept and slope parameters are close to zero for both the full period and the post 1975 period. Futures price changes appear to have little ability to predict cash price changes. The ability of the lagged futures price/cash price difference to explain current cash price (Table 4, panel B) is somewhat stronger with slope parameters that are statistically significantly different from zero and not statistically significantly different from one in either sample period. The equation residuals appear to be well behaved with little evidence of auto-correlation.

Before error correction models can be estimated, it is necessary to identify the number of cointegrating vectors that exist between the variables, futures price, cash price, interest rate, inventory, cash price return standard deviation

Table 2
Auto-correlation over levels and change in levels[a]

	r_1	r_2	r_3	r_4	r_5	r_{12}	r_{24}
UK treasury bill 3-month interest rates							
Levels — C.C.R.	0.91	0.80	0.68	0.59	0.49	0.06	0.21
Δ Levels — C.C.R.	0.11	0.04	−0.15	0.03	−0.15	0.12	0.10
Inventory							
Levels — natural log	0.94	0.86	0.79	0.71	0.64	0.28	0.07
Δ Levels — natural log	0.23	−0.11	−0.09	−0.07	−0.07	−0.04	−0.09
Cash price							
Levels — natural log	0.96	0.93	0.88	0.83	0.79	0.60	0.26
Δ Levels — natural log	−0.01	0.09	0.03	−0.08	−0.21	0.03	−0.11
3-month futures price							
Levels — natural log	0.97	0.93	0.89	0.85	0.81	0.62	0.26
Δ Levels — natural log	0.03	0.04	0.03	−0.03	−0.23	0.06	−0.05
Cash price return standard deviation per day							
Levels — natural log	0.43	0.36	0.20	0.19	0.15	0.16	0.04
Δ Levels — natural log	−0.44	0.09	−0.14	0.03	−0.06	−0.00	−0.05
Cash price return first order auto-correlation coefficient							
Levels	0.01	0.05	0.08	0.08	−0.03	0.02	0.00
Δ Levels	−0.51	0.00	0.00	0.07	−0.09	−0.00	−0.01

[a] Total sample consists of quarterly observations with $N=123$. The coefficient, r_i, is the ith order auto-correlation coefficient.

and cash price return first order auto-correlation coefficient. Theory clearly identifies one cointegrating vector based on the cost of carrying the asset but ultimately this could be regarded as an empirical question. The Johansen test (Johansen, 1988; Johansen & Juselius, 1990) has been used in tests of market efficiency where the test focuses on cointegration between the futures price and the cash price. In both Krehbiel and Adkins (1993) and Crowder and Hamed (1993) cointegration between the cash and futures price is rejected while rejection is also observed with analyses based on the simpler Engle and Granger (1987) approach (Chowdhury, 1991; MacDonald & Taylor, 1988a). The level of rejection may not be surprising given Eqs. (6) and (8) above. If the variables determining the cost of carry are non-stationary, a cointegrating relationship may exist between futures price, cash price and the carrying cost variables rather than just futures price and cash price alone. Eqs. (6) and (8) also involve implicit assumptions about weak exogeneity of the lagged futures price and the carrying cost variables. (The impact of exogeneity is drawn out in Ericsson (1992).)

Results from the Engle and Granger test and the Johansen test are reported in Table 5, panel A and panel B, respectively. Augmented Dickey–Fuller tests are reported for the Engle and Granger cointegration test with statistics reported for three lag choices, 1 lag, 2 lags and 4 lags. In all cases the null of no cointegration is rejected in favour of the alternative of cointegration, though this test provides little indication of whether there is more than one cointegrating vector. Given the six variable vector autoregression in Eq. (12) with four non-stationary

Table 3
Unit root tests — augmented Dickey–Fuller test statistic, $Z(t_a)$

	Levels			Change in levels		
	1 lag	2 lags	4 lags	1 lag	2 lags	4 lags
UK treasury bill 3-month interest rates (C.C.R.)	−2.52	−2.72	−2.59	−7.06*	−6.92*	−5.63*
Natural log of the inventory (tonnes)	−3.28	−2.83	−2.93	−7.91*	−6.51*	−5.29*
Natural log of the cash price (GBP)	−2.19	−2.38	−2.30	−7.14*	−5.70*	−6.09*
Natural log of the 3-month futures price (GBP)	−2.08	−2.18	−2.22	−7.29*	−5.81*	−6.00*
Cash price return standard deviation per day	−5.50*	−5.17*	−4.22*	−10.42*	−9.05*	−7.53*
Cash price return first order auto-correlation coefficient	−7.61*	−5.85*	−4.67*	−13.72*	−11.27*	−7.97*

*Statistically significant at the 5% level of significance. Total sample consists of quarterly observations with $N = 123$. The model includes intercept and time trend. These tests are also conducted using a model that includes intercept, but no time trend, with little change in results. The t-statistic is reported for the augmented Dickey–Fuller test. Critical values for the 5% level of significance for the t-statistic used in the augmented Dickey–Fuller test is −3.41 (Fuller, 1976). Number of lags used in the test is indicated in the column heading.

variables and two stationary variables, it is expected that the error correction parameter matrix will have a rank of three at least given that the cost of carry relationship holds. Panel B of Table 5 identifies four cointegrating vectors in the system using either the trace statistic or the Maximal value statistic. (The Poskitt (2000) test also identified a rank of four for this matrix. This test is essentially a non-parametric test and provides a useful check on the results of the Johansen test.)

The results for the Brenner and Kroner (1995) regression model, based on Eq. (6), are reported in Table 6. The results generally support the Brenner and Kroner (1995) argument that the costs of carrying the underlying asset have an impact on the cash price and thus on the ability of the current futures price to predict cash prices. While the parameter for the futures price change is positive and statistically significant, the parameters for the change in inventory and the error correction term parameter are statistically significant and negatively signed. These parameter estimates are consistent with the cost of carry model. The results are not so clear for the interest rate, standard deviation and first order serial correlation parameters. For the change in standard deviation and the change in first order auto-correlation coefficient the parameters are not statistically significant and the parameter signs for these variables change with sample choice. There is also some variation in the elements of the cointegrating vector when comparing the full period with the post 1975 period. To provide some indication of the stability of the model over the study period CUSUM and CUSUMSQ graphs are reported in Figs. 6 and 7, respectively. These graphs suggest that the Brenner and Kroner (1995) model is fairly stable over the period. (Similar results

Table 4
Ordinary least squares regression

	Full period	Post 1975
Panel A: regression of cash price change on lagged futures price change[a]		
Intercept	0.008	0.011
	(0.7)	(0.7)
Futures price change	0.015	0.008
	(0.1)	(0.1)
R^2	0.00	0.00
F test	0.02	0.00
Durbin–Watson statistic	1.94	2.05
Auto-correlation in e, χ^2 statistic (12)	16.63	19.56
Auto-correlation in e^2, χ^2 statistic (12)	7.60	5.18
Panel B: regression of cash price change on lagged difference between futures price and cash price[b]		
Intercept	0.006	0.004
	(0.5)	(0.2)
Futures price less cash price parameter	1.009*	0.823*
	(3.1)	(2.1)
R^2	0.07	0.06
F test	9.44*	4.43*
Durbin–Watson statistic	1.92	1.88
Auto-correlation in e, χ^2 statistic (12)	13.48	16.43
Auto-correlation in e^2, χ^2 statistic (12)	11.86	5.93

[a] *Statistically significant at the 5% level of significance. Total sample consists of quarterly observations with $N=123$. The regression takes the form:$DP_t = a_0 + a_1 DF_{t|t-1} + e_t$where Dx is the change in the variable x, $F_{t|t-k}$ is the natural log of futures price at time $t-k$ for contract maturing at time t, P_t is the natural log of cash price at time t, e_t is the residual term. Ordinary least squares is used for all regressions with the OLS t-statistics in parentheses. Critical value for the chi-square test is 21.026. Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

[b] *Statistically significant at the 5% level of significance. Total sample consists of quarterly observations with $N=123$. The regression takes the form:$DP_t = b_0 + b_1(F_{t|t-1} - P_{t-1}) + e_t$where Dx is the change in the variable x, $F_{t|t-k}$ is the natural log of futures price at time $t-k$ for contract maturing at time t, P_t is the natural log of cash price at time t, e_t is the residual term. Ordinary least squares is used for all regressions with the OLS t-statistics in parentheses. Critical value for the chi-square test is 21.026. Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

are obtained for the other regressions reported here.) Thus although there is some variation in the parameter estimates, this variation does not appear critical to the performance of the model.

Table 7 describes the vector error correction model with one cointegrating vector (panel A) and four cointegrating vectors (panel B). The simple one cointegrating vector model constrains the error correction term to the cost of carry relationship. There is little theoretical reason for including more than one cointegrating vector and so this model provides a base case for comparison with the more complex four cointegrating vectors model. It is interesting to note the lack of statistical significance of the speed of adjustment terms in this model, as reported in panel A, especially given the Engle and Granger tests and the relatively strong

Table 5
Tests for cointegration

		1 lag	2 lags	4 lags
Panel A: Engle and Granger test using the augmented Dickey–Fuller test[a]				
B&K ECT		−7.08*	−5.89*	−5.49*
Std ECT		−6.93*	−5.86*	−4.79*
$H0{:}r$	Statistics		Critical values (95%)	
	Trace	L-max	Trace	L-max
Panel B: Johansen test for cointegration vectors[b]				
0	186.82*	55.18*	101.84	26.10
1	131.65*	47.83*	75.74	22.31
2	83.82*	46.40*	53.42	18.63
3	37.42*	23.36*	34.80	14.80
4	14.06	10.71	19.99	10.86
5	3.34	3.34	9.13	9.13

[a] *Statistically significant at the 5% level of significance with critical value at the 5% level of −3.81 (critical value from MacKinnon's response surface tables reported in Banerjee et al. (1993, p. 213)). Augmented Dickey–Fuller tests are conducted on the residuals from the Brenner and Kroner (1995) model (B&K ECT), estimated using OLS (OLS standard errors are in parentheses):

$$P_t = \underset{(0.2434)}{0.1925} + \underset{(0.0452)}{0.9686} F_{t|t-1} - \underset{(2.3503)}{0.6648} r_{t|t-1} - \underset{(0.0153)}{0.0029} I_{t|t-1} + \underset{(0.0293)}{0.0064} \sigma_{t-1} - \underset{(0.0558)}{0.0642} \rho(1)_{t-1} + e_t$$

and the standard error correction model (Std ECT), estimated using OLS (OLS standard errors are in parentheses):

$$P_t = \underset{(0.0461)}{0.1552} + \underset{(0.0086)}{1.0478} F_{t+1|t} + -\underset{(0.4450)}{2.1124} r_{t+1|t} - \underset{(0.0029)}{0.0315} I_{t+1|t} + \underset{(0.0056)}{0.0096} \sigma_t - \underset{(0.0106)}{0.0064} \rho(1)_t + e_t.$$

The residuals from these regressions are stationary in all cases indicating cointegration exists between the sets of variables. P_t is the cash price observed at time t, $F_{t+1|t}$ is the futures price observed at time t maturing at time $t+2$, $r_{t+1|t}$ is the interest rate observed at time t maturing at time $t+1$, I_t is the inventory observed at time t, σ_t is the standard deviation of cash price returns observed at time t estimated using the 20 preceding daily cash price returns, ρ_t is the first order auto-correlation coefficient of cash price returns observed at time t estimated using the 20 preceding daily cash price returns. Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

[b] *Statistically significant at the 5% level of significance. The Johansen test is run over cash price, futures price, interest rate, inventory, standard deviation of cash price returns and first order auto-correlation coefficient of cash price returns. Inclusion of the stationary variables, standard deviation and first order auto-correlation, increase the rank of the cointegration space by two. Given Figs. 1 to 5 no intercept term is included in the VAR though an intercept is included in the cointegrating vector in line with the need to capture fixed storage costs and convenience yield effects. The final model used in the Johansen (1988) test takes the form: $DX_t = M_1 DX_{t-1} + S' ECT^{*}_{t-2} + E_t$ where DX_t is the change in vector X_t, M_1 is the matrix of parameters, S is the vector of speed of adjustment parameters, ECT^{*}_{t-2} is a vector containing the variables in levels as well as a constant term, and E_t is the vector of residuals. Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

performance of this model in forecasting (reported below). The four cointegrating vectors error correction model includes the cointegrating vectors identified in the Johansen test reported in Table 6. The four cointegrating vectors model suggests a more complex model than initially expected though this additional complication appears to be driven by the cost of carry elements, consistent with the argument of Brenner and Kroner (1995).

Table 6
Brenner and Kroner (1995) model, testing the explanatory power of the cost of carry components over future cash price

	Full period	Post 1975
Intercept	0.000	0.000
	(0.0)	(0.0)
Futures price change	1.220*	0.962*
	(4.2)	(4.1)
Risk free rate change	7.525*	1.540
	(2.0)	(0.4)
Inventory change	−0.110*	−0.149*
	(−3.1)	(−3.2)
Standard deviation change	0.016	−0.009
	(0.7)	(−0.3)
First order auto-correlation coefficient change	0.061	−0.016
	(1.6)	(−0.3)
Error correction term	−1.285*	−1.116*
	(−4.6)	(−4.6)
R^2	0.22	0.28
F test	5.50*	4.62*
Durbin–Watson statistic	1.98	2.01
Auto-correlation in e, χ^2 statistic (12)	3.82	6.82
Auto-correlation in e^2, χ^2 statistic (12)	6.89	13.65

*Statistically significant at the 5% level of significance. Ordinary least squares is used for all regressions with the bracketed term the OLS *t*-statistic. Critical value for the chi-square test is 21.026. The cost of carry based model in the form suggested by Brenner and Kroner (1995):

$$DP_t = g_0 + g_1 DF_{t|t-1} + g_2 Dr_{t|t-1} + g_3 DI_{t-1} + g_4 D\sigma_{t-1} + g_5 D\rho(1)_{t-1} + g_6 ECT_{t-2} + e_t,$$

where Dx is the change in the variable x, $F_{t|t-k}$ is the natural log of futures price at time $t-k$ for contract maturing at time t, P_t is the natural log of cash price at time t, $r_{t|t-k}$ is the interest rate for the period $t-k$ to t known at time $t-k$, I_{t-k} is the inventory at time $t-k$, e_t is the residual term, σ_{t-2} is the standard deviation of cash price returns time $t-2$ estimated using the 20 preceding daily cash price returns, ρ_{t-2} is the first order auto-correlation coefficient of cash price returns observed at time $t-2$ estimated using the 20 preceding daily cash price returns. The ECT_{t-2} term is the residual, e_t, from Eq. (7) and the cointegrating vector is estimated as:

	Cointegrating vector full sample	Cointegrating vector post 1975
Spot price	1.0000	1.0000
Futures price	−0.9686	−0.7737
Risk free rate	0.6648	4.6336
Inventory	−0.0029	0.0616
S.D.	−0.0064	0.0005
$\rho(1)$	−0.0642	0.0043
Constant term	−0.1925	−2.1243

Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

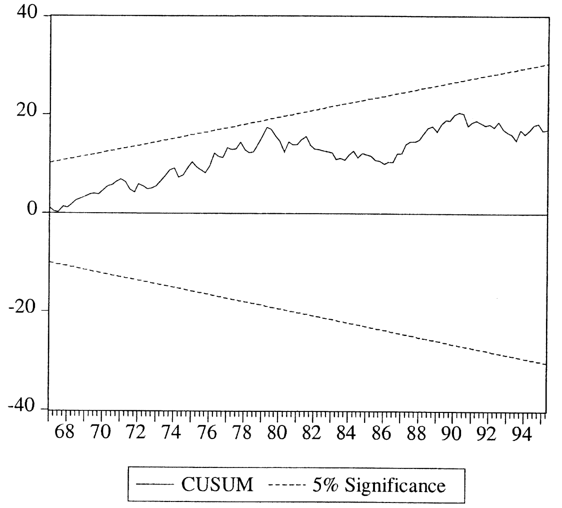

Fig. 6. Stability-scaled recursive residual based tests CUSUM. Recursive residuals used in the calculation of the CUSUM are obtained from the cost of carry based model suggested by Brenner and Kroner (1995) with carrying costs including interest rate to maturity, current inventory and a constant term.

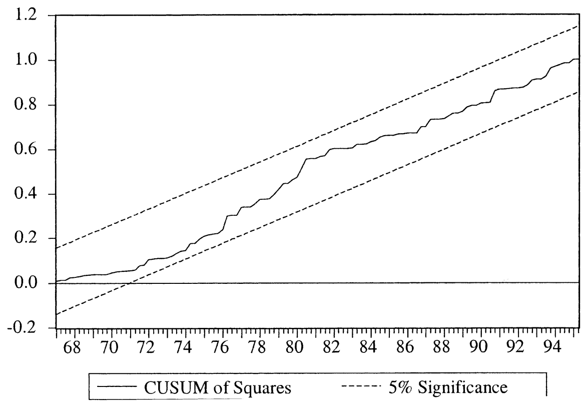

Fig. 7. Stability-scaled recursive residual based tests CUSUMSQ. Recursive residuals used in the calculation of the CUSUM are obtained from the cost of carry based model suggested by Brenner and Kroner (1995) with carrying costs including interest rate to maturity, current inventory and a constant term.

Focusing on the spot price equation, the statistically significant parameters, change in futures price, change in spot price and change in inventory appear consistent with the cost of carry model. Further, the signs of the single equation cointegrating vector parameters, panel A, are also consistent with the cost of carry model. In the four cointegrating vectors model, panel B, two vectors appear to load on the spot price equation, vectors 2 and 4, and both vectors exhibit parameter signs consistent with the cost of carry model though the magnitude of the parameters varies considerably. It is important to note that the speed of adjustment for the second cointegrating vector is negative, as expected, though the speed of adjustment parameter for the fourth cointegrating vector has a positive sign.

5. Comparison of model predictions

Table 8 reports one step ahead forecasts using differing estimation periods, forecast horizons and models. The models used in this comparison include the two variable OLS models (OLS-1 and OLS-2), the Brenner and Kroner model (B&K) and two versions of the vector error correction models, the first using one cointegrating vector obtained from the Engle and Granger test (VECM–one CV) and second using four cointegrating vectors obtained from the Johansen procedure (VECM–four CVs). Forecast accuracy is measured in terms of mean error, mean absolute error and mean squared error. The error is defined as actual change in log cash price less the predicted change in log cash price. The mean error provides a measure of bias in the predictions as it is a measure of the average difference. Mean squared error and mean absolute error provide measures of the spread or variation in the prediction errors.

Panel A is based on forecast models estimated using the complete data set with 'predictions' being made within the estimation sample period. The vector error correction models perform most strongly, with least bias and least variation in prediction errors. Given the number

Table 7
Cost of carry vector correction models

Equation	DF	DP	Dr	DI	DS	DC
Panel A: vector error correction model — one cointegrating vector[a]						
Lag change in futures price (DF)	0.202	1.242*	0.002	−2.000	2.866	0.228
	(0.4)	(2.4)	(0.2)	(−1.6)	(1.4)	(0.3)
Lag change in cash price (DP)	−0.215	−1.227*	0.003	1.572	−2.490	−0.218
	(−0.5)	(−2.5)	(0.3)	(1.3)	(−1.4)	(−0.2)
Lag change in interest rate (Dr)	5.837	5.07	0.078	−11.325	15.847	−3.971
	(1.6)	(1.3)	(0.8)	(−1.2)	(1.1)	(−0.5)
Lag change in inventory (DI)	−0.077*	−0.128*	−0.001	0.269*	−0.207	0.097
	(−2.02)	(−3.1)	(−0.7)	(2.7)	(−1.3)	(1.2)
Lag change in S.D. (DS)	0.022	0.020	−0.000	0.048	−0.408*	−0.044
	(1.03)	(0.9)	(−0.5)	(0.8)	(−4.6)	(−0.9)
Lag change in $\rho(1)$ (DC)	0.026	0.023	0.001	−0.085	−0.007	−0.503*
	(0.7)	(0.6)	(1.3)	(−0.9)	(−0.0)	(6.3)
Constant	0.012	0.012	−0.000	0.024	−0.003	−0.006
	(1.1)	(1.0)	(−0.1)	(0.9)	(0.1)	(−0.2)
Error correction term	−0.104	−1.009	0.005	1.086	0.957	0.510
	(−0.2)	(−1.5)	(0.3)	(0.7)	(0.4)	(0.4)
R^2	0.08	0.13	0.08	0.12	0.25	0.30
Durbin–Watson statistic	1.94	1.90	2.00	1.95	2.14	2.39

[a] *Statistically significant at the 5% level of significance. The *t*-statistic is reported in parentheses immediately below the parameter estimate. DF is the change in futures price, DP is the change in cash price, Dr is the change in interest rate, DI is the change in inventory, DS is the change in cash price return standard deviation and DC is the change in cash price first order correlation coefficient. The vector error correction model takes the following form:

$$DX_t = M_1 DX_{t-1} + S' ECT^*_{t-2} + L + E_t.$$

DX_t is the change in vector X_t, M_1 is the matrix of parameters, S is the vector of speed of adjustment parameters, L is a vector of constant terms and E_t is the vector of residuals. ECT^*_{t-2} are the residuals, e_t, from Eq. (9) and the cointegrating vector is estimated as:

	Cointegrating vector
Spot price	1.0000
Futures price	−1.0478
Risk free rate	2.1124
Inventory	0.0315
S.D.	−0.0096
$\rho(1)$	0.0064
Constant term	−0.1552

Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

of parameters in these models this result is not unexpected and could be driven by 'over-fitting'. Panels B, C and D provide examples of holdout sample 'one step ahead' predictions where the model is estimated once over the selected estimation period and the estimated parameters are then used in cash price change prediction over the 'holdout period'. The ECMs perform most consistently with least variation in prediction errors and comparatively low bias for each of the three holdout periods, 42 quarters, 22 quarters and 12 quarters. The Brenner and Kroner model exhibits least mean square error while the vector error correction model with one

Table 7. Continued

Equation	DF	DP	Dr	DI	DS	DC
Panel B: vector error correction model — four cointegrating vectors[b]						
Lag change in futures price (DF)	0.190	1.235*	0.006	−1.880	3.956*	0.882
	(0.4)	(2.5)	(0.5)	(−1.5)	(2.4)	(1.0)
Lag change in cash price (DP)	−0.261	−1.284*	0.001	1.589	−3.255*	−0.709
	(−0.6)	(−2.7)	(0.1)	(1.4)	(−2.1)	(−0.9)
Lag change in interest rate (Dr)	9.399*	9.078*	−0.021	−16.285	12.758	−2.223
	(2.4)	(2.20)	(−0.2)	(−1.6)	(1.0)	(−0.3)
Lag change in inventory (DI)	−0.069	−0.118*	−0.001	0.218*	−0.238*	−0.021
	(−1.8)	(−2.9)	(−1.0)	(2.2)	(−1.8)	(−0.3)
Lag change in S.D. (DS)	0.016	0.008	0.000	0.029	−0.858*	−0.065
	(0.6)	(0.3)	(0.3)	(0.4)	(−8.9)	(−1.2)
Lag change in $\rho(1)$ (DC)	0.033	0.032	0.001	−0.260	−0.027	−0.989*
	(0.6)	(0.6)	(0.7)	(−1.9)	(−0.2)	(−10.2)
Constant	0.008	0.008	0.000	0.029	−0.002	−0.008
	(0.8)	(0.7)	(0.3)	(1.0)	(−0.1)	(−0.4)
Cointegrating vector 1	0.016	0.019	−0.001	−0.187*	−0.342*	−0.421*
	(0.5)	(0.5)	(−0.6)	(−2.1)	(−2.9)	(−6.5)
Cointegrating vector 2	−0.387	−0.694*	0.007	0.863	−6.036*	0.990
	(−1.3)	(−2.3)	(1.0)	(1.1)	(−6.0)	(1.8)
Cointegrating vector 3	−0.221	−0.866	0.005	0.940	5.214*	−1.215
	(−0.4)	(−1.6)	(0.4)	(0.7)	(3.0)	(−1.3)
Cointegrating vector 4	0.352*	0.361*	−0.009*	−0.380	0.086	0.368
	(2.6)	(2.5)	(−2.8)	(−1.1)	(0.2)	(1.5)
R^2	0.15	0.21	0.15	0.17	0.50	0.51
Durbin–Watson statistic	2.01	1.99	1.99	2.02	2.02	2.02

[b] *Statistically significant at the 5% level of significance. The t-statistic is reported in parentheses immediately below the parameter estimate. DF is the change in futures price, DP is the change in cash price, Dr is the change in interest rate, DI is the change in inventory, DS is the change in cash price return standard deviation and DC is the change in cash price first order correlation coefficient. The vector error correction model takes the following form:

$$DX_t = M_1 DX_{t-1} + S'ECT^{*}_{t-2} + L + E_t.$$

DX_t is the change in vector X_t, M_1 is the matrix of parameters, S is the vector of speed of adjustment parameters, L is a vector of constant terms and E_t is the vector of residuals. ECT^{*}_{t-2} are the error terms, e_t, calculated using the cointegrating vectors associated with the four largest eigen values obtained from the Johansen procedure. The cointegrating vectors are:

	Cointegrating vector 1	Cointegrating vector 2	Cointegrating vector 3	Cointegrating vector 4
Spot price	1.0000	1.0000	1.0000	1.0000
Futures price	−1.4584	−1.0897	−1.0225	−1.3247
Risk free rate	1.0264	1.4652	1.8248	14.1260
Inventory	0.1719	0.0249	0.0257	0.1287
S.D.	0.5034	0.0876	−0.0358	0.0321
$\rho(1)$	1.8707	−0.0857	0.0466	−0.0782
Constant term	2.9270	0.5712	−0.3376	0.2476

Quarterly observations are drawn from the period 30 October 1964 to 14 September 1995.

cointegrating vector generally shows least bias and least mean absolute error. Similar results are observed when allowance is made for re-estimating the model parameters after each forecast (panel E in Table 8). The simple regressions based on cash and futures prices

Table 8
One step ahead rate of return forecast accuracy

Forecast models	Mean error (rate of return)	Mean absolute error (rate of return)	Mean square error (rate of return)
Panel A: model fitted to 1964:4 to 1995:2, forecast within sample 1985:1 to 1995:2 (42 observations)			
OLS-1	−0.008	0.104	0.017
OLS-2	−0.010	0.098	0.015
B&K	0.010	0.092	0.013[a]
VECM–one CV	−0.001[a]	0.091[a]	0.014
VECM–four CVs	0.003	0.094	0.014
Panel B: model fitted to 1965:1 to 1984:4, forecast out of sample 1985:1 to 1995:2 (42 observations)			
OLS-1	−0.012	0.106	0.018
OLS-2	−0.015	0.098	0.016
B&K	0.011	0.097	0.014[a]
VECM–one CV	−0.001[a]	0.096[a]	0.015
VECM–four CVs	−0.004	0.102	0.017
Panel C: model fitted to 1965:1 to 1989:4, forecast out of sample 1990:1 to 1995:2 (22 observations)			
OLS-1	−0.016	0.115	0.019
OLS-2	−0.047	0.117	0.020
B&K	−0.028	0.109	0.018[a]
VECM–one CV	−0.006[a]	0.107[a]	0.019
VECM–four CVs	−0.029	0.112	0.020
Panel D: model fitted to 1965:1 to 1992:2, forecast out of sample 1992:3 to 1995:2 (12 observations)			
OLS-1	0.017	0.123	0.021
OLS-2	−0.017	0.122	0.019
B&K	−0.014[a]	0.118	0.018[a]
VECM–one CV	0.027	0.118[a]	0.020
VECM–four CVs	0.020	0.119	0.020
Panel E: model fitted to 1965:1 to 1984:4 initially and then updated with each forecast generating one period ahead out of sample forecasts through to 1995:2 (42 observations)			
OLS-1	−0.008	0.106	0.018
OLS-2	−0.012	0.099	0.016
B&K	0.013	0.097	0.015[a]
VECM–one CV	0.000[a]	0.097[a]	0.015
VECM–four CVs	0.006	0.101	0.017

[a] The lowest metric value. The forecast models provide one step ahead predictions of the continuously compounding rate of the return for comparison with actual continuously compounding rate of the return in cash price. The total sample consists of 123 quarterly observations. Mean error, average of the actual change in log price less predicted change in log price; mean absolute error, average of the absolute value of the difference between the actual change in log price and the predicted change in log price; mean square error, average of the actual change in log price less predicted change in log price squared.

alone do not outperform either the Brenner and Kroner model or the vector error correction model with one cointegrating vector in any of the comparisons.

It is important to note the performance of the vector error correction model with four cointegrating vectors. This model rarely out-ranks the simpler one cointegrating vector models though it is often superior to the simpler regressions based on cash and futures price alone. Perhaps estimation of the additional cointegrating vectors, although statistically important, has resulted in over-fitting.

The various approaches to estimation of one step ahead prediction errors emphasise the robustness of the single cointegrating vector error correction models. They exhibit both least bias and least variance in one period ahead prediction. The single cointegrating vector ECM generally shows least bias and least average absolute error while the Brenner and Kroner model generally shows least mean square error. Inclusion of cost of carry information appears to improve in sample and out of sample forecasting ability.

6. Conclusions

This paper provides a test of the ability of futures prices to predict subsequent cash price where allowance is made for the impact of carrying costs. The analysis uses matched quarterly inventory, UK Treasury bill interest rates, futures prices and cash prices for the commodity lead traded on the London Metal Exchange (LME). Cash price return standard deviation and first order auto-correlation coefficients are also estimated and included in analysis. The cash price, futures price and inventory are all obtained from the same market and reported futures prices have a fixed time to maturity of 3 months.

The null of unit root process cannot be rejected for futures price, cash price, interest rate and inventory level over the full period though cash price return standard deviation and first order auto-correlation coefficients are found to be stationary. Single equation error correction models indicate a statistically significant relationship between the cost of carry pricing discrepancies in previous periods and the current cash price change. This result is supportive of the predictions of Brenner and Kroner (1995). Further, there is evidence of statistically significant short run effects including a negative relationship between cash price change and lagged inventory level change and a positive relationship between cash price change and lagged change in futures price.

Finally, tests of the ability of futures price to predict subsequent cash price over various holdout periods favour models that include carrying costs. The single cointegrating vector error correction model exhibits least mean error and mean absolute error while the Brenner and Kroner model generally exhibits least mean squared error. The cash price is quite volatile from quarter to quarter and there is considerable variation left unexplained by the various models. Thus there is still much to do towards improving the predictive and explanatory power of these models. Perhaps further improvement will flow from more precise modelling of the cost of carry model.

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