ECONOMETRIC MODELLING OF NON-FERROUS METALS PRICES

Clinton Watkins
Akita International University
国際教養大学

公立大学法人
国際教養大学
Akita International University

Today I plan to talk about…

- Econometric modelling of non-ferrous metals prices

  Clinton Watkins and Michael McAleer

  Journal of Economic Surveys, Vol. 18, No. 5, 2004

- Pricing of non-ferrous metals futures on the London Metal Exchange

  Clinton Watkins and Michael McAleer

  Applied Financial Economics, Vol 16, 2006

Econometric modelling of non-ferrous metals prices

Clinton Watkins and Michael McAleer

Journal of Economic Surveys, Vol. 18, No. 5, 2004

Aim of the paper

- Evaluate the “empirical significance” of econometric modelling in metals markets
  - Exchange-based trading of industrially-used non-ferrous metals
    - Aluminium, copper, nickel, lead, tin, zinc
    - Not precious metals like gold, silver
- Meta analysis criteria
  - What has been published, where and when?
  - What types of economic hypothesis have been tested?
  - What data has been used?
    - Metal, exchange, type of financial product, sample size.
  - What do the empirical models look like?
    - Type of model, variables, estimation methods
  - How have these models been evaluated?
    - Descriptive statistics, diagnostic tests, tests between models

Background

- 45 published articles over the period 1980-2002.
- Academic interest in exchange based trading of industrial metals grew over this period as exchange trading became more prevalent for both producers and consumers of metals, as well as investors/speculators.
  - Prior to this, “producer list pricing” was more prevalent for most metals
  - Exchange based metals trading was initially almost exclusively the realm of producers and consumers of metals
  - Over time, investors/speculators have shown a greater interest in industrial metals
    - Appetite for assets uncorrelated with the traditional asset classes
    - Exchange products have become more amenable to investors

Table 1. Journals Publishing Research on Non-Ferrous Metals.

Journal	Number of papers
Applied Economics	6
Applied Economics Letters	1
Applied Financial Economics	1
Bell Journal of Economics	1
Bulletin of Economic Research	2
Economics Letters	1
European Journal of Finance	1
International Economic Review	1
International Journal of Forecasting	1
Kentucky Journal of Economics and Business	1
Journal of Applied Econometrics	1
Journal of Banking and Finance	1
Journal of Business	1
Journal of Finance	2
Journal of Financial Economics	1
Journal of Futures Markets	10
Journal of Money, Credit and Banking	1
Managing Metals Price Risk*	1
Oxford Bulletin of Economics and Statistics	1
Quarterly Journal of Economics	1
Resources Policy	3
Review of Financial Economics	1
Review of Futures Markets	2
Revista de Analisis Economico	1
The Manchester School	2
Total (in 25 Journals)	45

*Chapter of an edited book rather than a journal.

Table 2. Publication Year For Research on Non-Ferrous Metals.

Year of publication	Number of papers
1980	1
1981	1
1982	1
1983	2
1984	0
1985	1
1986	3
1987	0
1988	4
1989	2
1990	4
1991	5
1992	2
1993	1
1994	2
1995	4
1996	0
1997	3
1998	2
1999	2
2000	0
2001	3
2002	2
Total	45

Economic hypotheses tested

- Four broad areas of empirical research
  - Market efficiency
    - Several studies looks for predictive relationships between metals as evidence of market inefficiency.
    - For example, a cointegrating relationship between two metals is presumed to violate the efficient markets hypothesis.
      - Parity relationships between metals.
      - However, Agbeyegbe (1992) argues cointegration between markets shows that unanticipated price movements dominate.
    - Speculative efficiency (unbiased expectations hypothesis) says futures prices are an unbiased predictor of spot prices, and spot and futures prices for a metal should be cointegrated.
      - Some studies take evidence supporting speculative efficiency to also support the efficient market hypothesis
      - However, Brenner & Kroner (1995) argue a systematic difference between spot and futures may be due to carrying costs.
    - Various approaches to evaluating efficiency in metals markets has created some confusion, and mixed empirical results.

Economic hypotheses tested

- Four broad areas of empirical research
  - Cost-of-carry model (and theory of storage)
    - Futures price equals spot price plus costs associated with storing the commodity minus the convenience yield associated with holding inventory (plus a marking-to-market term).
    - Generally supported.
  - Risk premia and volatility processes
    - Risk premium hypothesis says the futures price equals the spot price plus a risk premium. Research in this area focuses on detecting risk premia in futures prices, rather than estimating a risk premium model.
      - No tests between cost-of-carry and risk premium.
    - Modelling volatility gained interest as producers and consumers of metal claim metals spot and futures prices have become more volatile with increased involvement of speculative investors in metals markets.
      - Generally not supported.

Economic hypotheses tested

- Four broad areas of empirical research
  - Other areas, such as supply & demand fundamentals
    - Price volatility is higher during periods of low inventory
    - Asymmetric response of prices to shocks during periods of low and high inventories
    - Price cycles in metals markets associated with business cycles
      - Supply of metals is inelastic in the short run
    - No fundamental value models for metals

Table 3. Economic Hypotheses Tested.

Economic hypothesis	Frequency
Efficient market hypothesis	13
Speculative efficiency hypothesis	8
Common (stochastic) trends	4
Theory of storage and cost-of-carry model	5
Speculation, hedging and volatility	2
Price and returns volatility processes	6
Risk premia and CAPM	1
Other futures market related	3
Other metals market fundamentals related	3
Total	45

Note: CAPM, Capital Asset Pricing Model.

Table 4. Source of Price Data.

Exchange	Frequency
CBOT	3
COMEX	7
KL Tin Exchange	2
LME	36
NCE	1
NYMEX	6
Presumably COMEX	1
Producer list price	3
SHME	1
Not stated	3
Total*	63

*Some studies used data from more than one exchange.
Notes: CBOT, Chicago Board of Trade; COMEX, Commodity Exchange of New York; LME, London Metal Exchange; NCE, xxxx; NYMEX, New York Mercantile Exchange; SHME, Shanghai Metal Exchange. Hill, More and Pruit (1991) obtain platinum prices from an exchange denoted NCE, but fail to provide its full name.

London Metal Exchange

- Most important exchange for industrial metals
  - Sets the global price of metals traded
- Has evolved over time
  - Initially participants were primarily consumers and producers of metal. Now investors are significant participants
- Unique features as a futures exchange
  - Contracts not marked-to-market until 1996
  - Clearing house only after International Tin Council collapse
  - New futures contract for each trading day
  - Delivery on a day not month
  - Spot transactions for each trading day
  - Contracts often result in delivery
  - Warehouse system in Europe, North America, Asia
  - Open outcry trading still very important for price discovery
  - Debate over whether LME contracts forwards or futures

Table 5. Metals Markets Analysed.

Metals markets modelled	Frequency
Aluminium	19
Aluminium Alloy	1
Copper	41
Gold	9
Lead	30
Nickel	13
Palladium	2
Platinum	6
Silver	13
Tin	24
Tungsten	1
Zinc	28
Total*	187

*Studies consider between one and nine metals markets.

Table 6. Type of Market Analysed.

Market type of focus	Frequency
Forward*	11
Forward* and futures	1
Futures	17
Spot	11
Spot and forward*	3
Spot and futures	2
Total	45

*LME futures markets are treated as forward markets by some authors.

Table 7. Sampling Frequency of Data.

Sampling frequency	Frequency
Intra-daily	0
Daily	12
Weekly	2
Monthly	24
Presumed monthly	1
Quarterly	6
4-Monthly	1
Annual	1
Total*	47

*One instance of both weekly and monthly and one instance of both 4-monthly and quarterly.

Table 8. Sample Sizes Used.

Number of observations	Frequency
<50	4
50–100	10
101–150	18
151–200	8
201–250	3
261–300	4
301–400	3
401–500	2
501–1000	2
1001–1500	2
1501–2000	1
2001–3000	3
3001–4000	1
>4001	4
Total*	65

*Some studies used more than one sample. In 13 papers where more than three samples are used, only the smallest and largest of the samples are reported.

Table 9. Dependent Variables.

Dependent variable	Frequency
Spot price	8
Log of spot price*	8
First difference in spot price	2
Futures or forward price†	5
Log of futures or forward price	2
First difference in futures or forward price	1
Producer price‡	2
Spot returns	8
Futures or forward returns	6
Realized futures or forward return	2
Variance of prices	3
Variance or covariance of returns	6
Log of futures or forward basis§	2
Forecast error	6
Log of forecast error	3
Production/consumption/stocks	5
Futures market volume variables	3
Interest rate variables	2
Excess gain variables	2
Exchange rate variables	1
No dependent variable indicated¶	4
Total**	81

*The spot price is adjusted using exchange rates in Gilbert (1995).
†Kocagil (1997) uses a detrended futures price.
‡One dichotomous dependent variable for producer pricing included.
§Includes interest-adjusted basis.
¶A dependent variable was not indicated for cointegration models estimated using the Johansen Maximum Likelihood method (Franses and Kofman, 1991; Agbeyegbe, 1992; Krehbiel and Adkins, 1993; Heaney, 1998).
**Some studies used more than one dependent variable.

Table 10. Choice of Explanatory Variable.

Type of explanatory variable	Frequency	
	Current	Lagged
Spot price*†	10	5
Log of spot price‡	3	2
First difference in spot price	0	1
Futures or forward price†	7	4
Log of futures or forward price	6	2
Log of futures to forward price ratio	1	0
First difference in futures or forward price	0	1
Producer price†	1	1
Spot returns	1	6
Futures or forward returns	0	4
Realized futures or forward return	0	1
Risk premium†	4	0
Convenience yield†	1	1
Variance or conditional variance of returns†	1	6
Futures or forward basis	2	0
Log of futures or forward basis§	1	4
Forecast error	1	5
Log of forecast error	1	1
First difference of forecast error	0	1
Production/consumption/stocks†	8	4
Returns on (metals) market portfolio†	2	0
Macroeconomic and metals sector variables†	11	0
Log of change in futures contract margins	1	0
(Risk-free) interest rate variables†	4	1
Exchange rate variables	0	1
Autocorrelation coefficient of spot returns	1	1
Producer price residual	1	0
Dummy variables	7	NA
Deterministic trend	1	NA
No explanatory variables indicated¶	2	NA

*One instance each of a deflated spot price and an expected spot price.
†Includes proxy variables and/or generated regressors.
‡In Gilbert (1995) the spot price is adjusted using an exchange rate index.
§The basis is adjusted for interest rate and storage in Ng and Pirrong (1994).
¶Labys *et al*. (1998) and McKenzie *et al*. (2001) do not indicate explanatory variables due to the use of structural time series models with nonstochastic regressors and a naïve model, respectively.

Proxy variables and generated regressors

- Futures price models frequently use unobservable var
  - Use proxy variable or generate a variable from another model
- Proxy variables
  - Measurement error and violate the exogeneity assumption
  - OLS estimates are biased and inconsistent
  - Model with one proxy: bias will be less than or equal to omitted variable bias.
  - More than one proxy: it may be better to exclude.
  - Use IV
- Generated regressors
  - Predicted values or residuals from another regression
  - Problems with efficiency and validity of estimates
  - Use a system of equations approach to estimation
- Metals literature generally doesn’t address these econometric issues

Table 11. Use of Proxy Variables and Generated Regressors.

Type of variable	Frequency	
	Proxy variable	Generated regressor
(Expected) Risk-free interest rate	4	0
Return on (metals) market portfolio	2	0
Inventory or stocks*	2	1
Convenience yield	2	0
Risk premium	0	4
Detrended futures price	0	1
Expected spot price	1	0
Production shock	0	1
Producer transactions price	0	1
Producer price residual	0	1
Metals price trend	1	0
Metals market fundamental characteristics	6	0
Unconditional variance of prices or returns	0	5
Conditional variance of returns	0	2

*Includes stock variables in levels, first difference, and the ratio of stocks to consumption trend (fitted value).

Table 12. Model Specification.

Model specification	Number of papers	Number of models
Linear regression	24	655
Nonlinear regression	1	12
Bivariate cointegration	7	57
Multivariate cointegration	5	10
Error correction	1	5
ARMA or ARIMA	7	23
Vector autoregression	2	14
Linear or nonlinear system of equations	4	9
Symmetric ARCH or GARCH	9	115
Asymmetric ARCH or GARCH	11	139
ARCH in mean or GARCH in mean	5	21
Fractionally integrated GARCH	1	6
DYMIMIC	1	4
Structural time series	2	23
Tobit or Probit	2	2
Total*	82	

*Some papers specified more than one model.

Table 13. Methods of Estimation.

Methods of estimation	Frequency
Ordinary least squares (OLS)	11
Presumably OLS	4
OLS with modified covariance matrix	10
Cochrane–Orcutt	5
GLS with modified covariance matrix	2
Feasible generalized least squares	1
Two-stage least squares	1
Three-stage least squares	1
IV with modified covariance matrix	1
Generalized instrumental variable estimator	3
Heckman two-step estimator	1
Nonlinear least squares	1
Presumably nonlinear least squares	1
Johansen maximum likelihood (ML) method	6
Engle–Granger method	6
ML	7
Presumably ML	5
Full information ML	1
Phillips–Hansen fully modified OLS	1
Kalman filter	2
Generalized method of moments	1
Total*	71

*Some studies used more than one method of estimation.

Descriptive statistics and diagnostic tests

- Descriptive statistics assess how well different models fit the data, with some adjustment for parsimony.
  - Each model is evaluated only in terms of its own performance, the principal disadvantage of discriminating between models on the basis of goodness of fit measures.
- Do the results of an econometric analysis reflect the assumptions made to specify the model, or the underlying economic theory? (Pesaran & Smith 1985)
- McAleer (1994) considers a linear regression model, and in the context of OLS, lists the following assumptions that require diagnostic testing:
  - (i) correct functional form, (ii) no heteroskedasticity, (iii) no serial correlation, (iv) exogeneity of the explanatory variables, (v) normality of the errors, (vi) parameter consistency, (vii) non-nested models (the model is adequate in the presence of non-nested alternative models) and (viii) robustness to departures from the auxiliary assumptions.

Table 14. Reported Descriptive Statistics.

Regression descriptive statistics	Reporting incidence
R^2 (including corrected and quasi-)	31
Standard error*	23
Standard error of equation	8
Log-likelihood	6
Information criteria	8
Regularity conditions	1
Correlogram	1
Skewness and kurtosis of standardized residuals	1
Forecast error measures	11
Forecast error variance	1
No descriptive statistics reported	5
Total†	96

*Includes standard errors of the following forms: White, Newev-West, Hansen and Hodenck, Hansen, Bollerslev and Wooldridge, asymptotic and approximate.
†Some papers reported more than one type of descriptive statistic.

Table 15. Reported Diagnostic Tests.

Diagnostic tests	Reporting incidence
No diagnostics reported	9
Serial correlation: Durbin–Watson or CRDW	16
Serial correlation: Bos–Pierce Q	4
Serial correlation: Ljung–Box	6
Serial correlation: other tests	12
Unit root	20
Structural change	5
Parameter stability	4
Linear trend	1
Misspecification	1
Normality	5
Heteroscedasticity	5
ARCH	1
Causality	1
Exogeneity	1
Multicollinearity	1
Presumably/predictive failure	1
Instrument validity	1
Intercept in a cointegrating vector	1
Total*	95

*Some studies used more than one type of diagnostic test.

Nested and non-nested testing

- Nested tests
  - Test restrictions on a general model containing alternatives.
- Non-nested tests
  - Achieve high power in testing the null model against a specific alternative.
  - Can the null model predict the alternative model significantly well?
- Little testing between alternative models in the literature on metals markets.

Table 16. Reported Nested and Non-Nested Tests.

Nested, non-nested and hypothesis tests	Reporting incidence
Nested tests	6
Non-nested tests	0
Hypothesis tests	27
Total*	33

*Some studies conducted both nested tests and hypothesis tests.

Pricing of non-ferrous metals futures on the London Metal Exchange

Clinton Watkins and Michael McAleer

Applied Financial Economics, Vol 16, 2006

Aim of the paper

- To provide a more accurate view of non-ferrous metal futures pricing.
  - No previous empirical studies testing between the cost-of-carry and risk premium models of futures pricing in a unified framework for metals markets.
  - A better understanding of futures pricing can be used to improve hedging and speculation decisions.

- London Metal Exchange is important in the metals markets, as it essentially sets the global prices for the main industrially-used non-ferrous metals.
  - Aluminium (Al), aluminium alloy (AA), copper (Cu), lead (Pb), nickel (Ni), tin (Sn), zinc (Zn).

Approach

- Taking advantage of the non-stationarity in the data, we estimate a general long-run futures pricing model within which two futures pricing models are nested, and conduct nested tests as restrictions on the general model.
  - Consider structural change or different regimes in pricing.
  - Test for unit roots in the data.
  - Estimate models using a cointegration framework.
  - Likelihood ratio tests of restrictions on the general model.
  - Consider each of the seven metals separately.

Use of cointegration

- Non-stationary data renders standard techniques that assume stationarity invalid – use cointegration.
- Reasonable to expect a long run relationship between commodity futures & spot prices (Chow et. al. 2000).
- No-arbitrage pricing models result in cointegrating relationships among price variables (Brenner and Kroner 1995).
- A large number of choices need to be made to determine the specification of the cointegrating VAR (Pesaran & Smith 1999).
  - Intercept and trend terms
  - Lag lengths
  - Exogenous variables
  - Judgement, economic theory to supplement statistical information

Models – risk premium hypothesis

- Under market efficiency and rational expectations, the futures price equals the expected future spot price plus a risk premium.

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

- Empirical form:

$$f_t = \alpha_0 + \alpha_1 s_{t+1} + \alpha_2 \pi_t + \varepsilon_t \qquad (2)$$

- The expected risk premium is unobservable, but expected to be stationary. Park and Phillips (1989) show stationary variables can be omitted from a cointegrating relationship.
- Zivot (1997) shows the risk premium model may be expressed in terms of spot at time t rather than t+1.

Models – cost-of-carry

- A no-arbitrage relationship that says the futures price equals the spot price plus storage costs minus convenience yield plus a marking-to-market term.
  - Storage costs include interest costs, physical costs of storage and a risk premium on inventory held.
  - Separating interest costs (r), we can think of the remaining storage costs net of convenience yield as c.

$$f_t = s_t + r_t - c_t + \theta_t \tag{3}$$

- Empirical form:

$$f_t = \beta_0 + \beta_1 s_t + \beta_2 r_t + \beta_3 c_t + \phi_t \tag{4}$$

- Storage cost net of convenience yield not observable, however has been argued by some to be stationary.
- Marking-to-market considered zero in the literature.

Models – cost-of-carry & general model

- Alternative cost-of-carry specification includes stock level effects (l).

$$f_t = s_t + r_t + w_t - l_t \qquad (5)$$

- Stock level effects are a linear function of inventory level (Heaney 1998) where $\delta > 0$ to be consistent with the behaviour of convenience yield.

$$l_t = \delta i_t - \gamma \qquad (6)$$

- Assuming storage costs (w) to be stationary, consistent with the approach in the literature, yields an empirically estimable general cost of carry model:

$$f_t = \eta_0 + \eta_1 s_t + \eta_2 r_t + \eta_3 i_t + \nu_t \qquad (7)$$

General model and nested alternatives

- Risk premium

$$f_t = \alpha_0 + \alpha_1 s_t + \varepsilon_t \tag{2}$$

- Cost of carry

$$f_t = \beta_0 + \beta_1 s_t + \beta_2 r_t + \phi_t \tag{4}$$

- General (& cost of carry with stock level effects)

$$f_t = \eta_0 + \eta_1 s_t + \eta_2 r_t + \eta_3 i_t + \nu_t \tag{7}$$

- (2) and (4) nested in (7)

Data

- Log of the daily LME spot and 3-month futures contract settlement prices in USD covering:
  - 1 February 1986 to 30 September 1999 (3473 observations) for aluminium, copper, lead, nickel and zinc
  - 12 December 1989 to 30 September 1999 for tin (2474)
  - 16 November 1993 to 30 September 1999 for aluminium alloy (1574)
- Log of the inventory level of all official LME warehouses for each metal in metric tons.
- Daily 3-month USD LIBOR for the risk-free rate.
- Some notes on the data:
  - Tin trade suspended from 1985 to 1989 due to the collapse of the International Tin Council.
  - Collapse of Sumitomo Corp's manipulation of the copper market in May 1996 (~obs 2600).
  - Several changes in LME contract specification over sample.

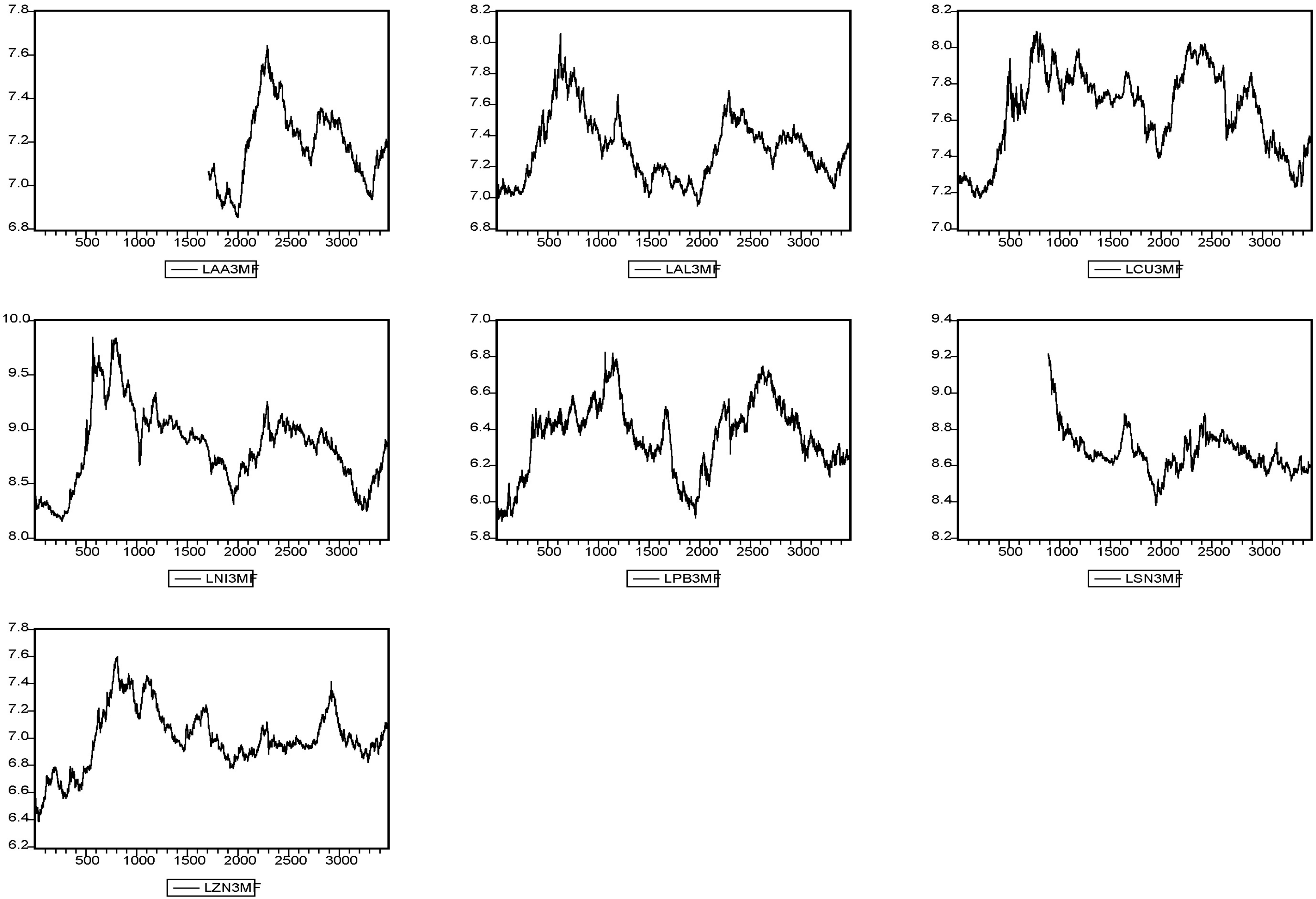
Approach to structural breaks

- As part of the analysis, we decided to separate the sample into different periods, or sub-samples.
  - Metals prices have long periods of up- and down-trends.
  - Metal supply is inelastic in the short-run, as mines and infrastructure take years to build. Higher prices induce new mining capacity, often to the extent that the market eventually becomes oversupplied for a substantial period.
- Futures pricing may differ between these periods.
  - Also unit root tests are generally biased toward non-rejection of the null in presence of structural breaks.
- Accordingly, we opted to determine sub-samples or structural break points visually, rather than by formal test.
  - Two sub-samples for aluminium alloy
  - Four sub-samples for aluminium, copper, lead, and nickel
  - Three sub-samples for tin and zinc

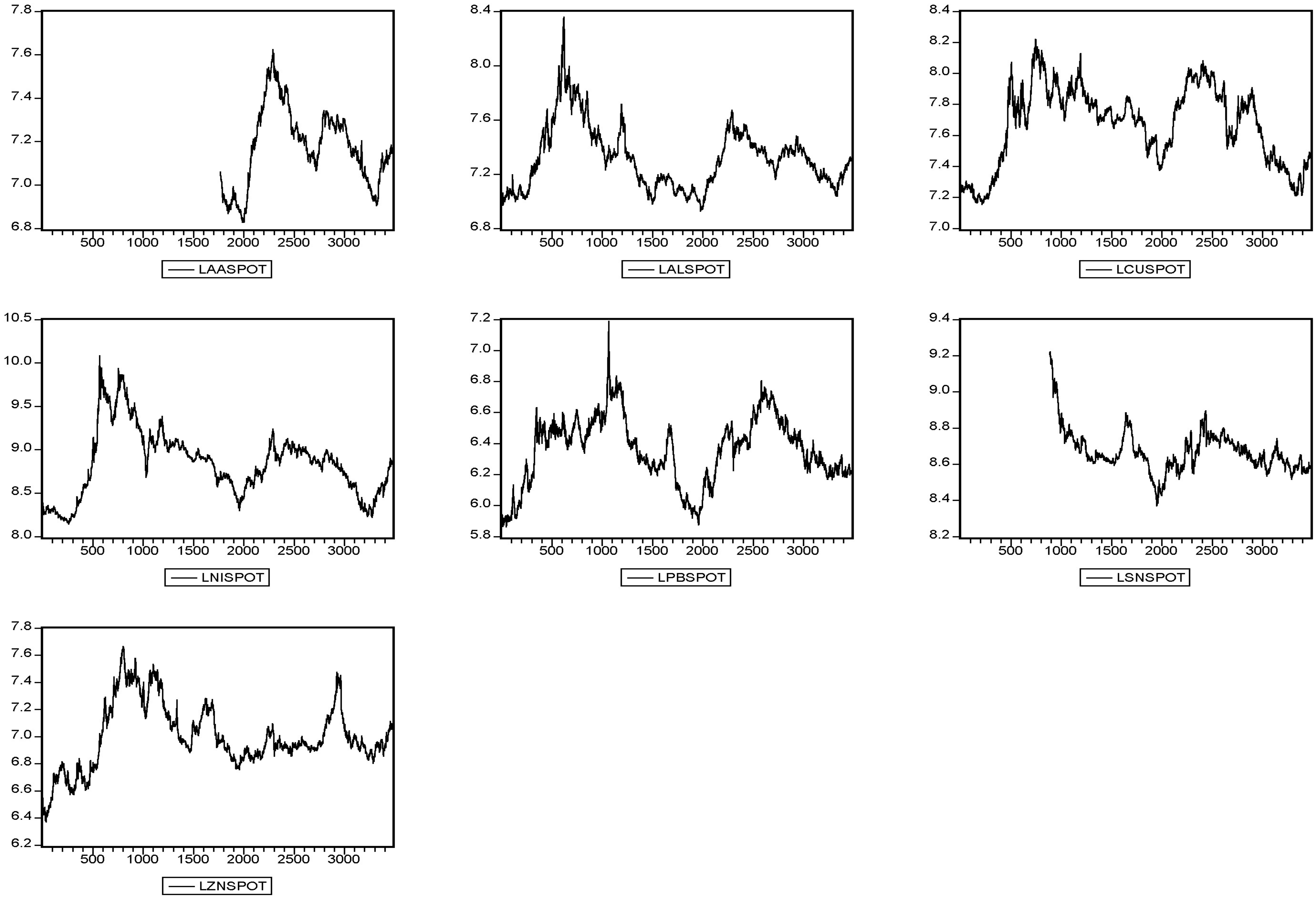
Table 1. Data and sub-samples

Market	Sample	Observations	Start date	Sample size
Aluminium alloy	Full sample	1990–3473	16-Nov-93	1574
	Sub-sample A	1990–2291	16-Nov-93	392
	Sub-sample B	2292–3473	27-Jan-95	1182
Aluminium	Full sample	1–3473	01-Feb-86	3473
	Sub-sample A	1–624	01-Feb-86	624
	Sub-sample B	625–1989	22-Jun-88	1365
	Sub-sample C	1990–2289	16-Nov-93	300
	Sub-sample D	2290–3473	25-Jan-95	1184
Copper	Full sample	1–3473	01-Feb-86	3473
	Sub-sample A	1–769	01-Feb-86	769
	Sub-sample B	770–1975	17-Jan-89	1206
	Sub-sample C	1976–2289	27-Oct-93	314
	Sub-sample D	2290–3473	25-Jan-95	1184
Lead	Full sample	1–3473	01-Feb-86	3473
	Sub-sample A	1–1141	01-Feb-86	1141
	Sub-sample B	1142–1959	07-Sep-90	818
	Sub-sample C	1960–2620	10-May-93	661
	Sub-sample D	2621–3473	17-May-96	853
Nickel	Full sample	1–3473	01-Feb-86	3473
	Sub-sample A	1–566	01-Feb-86	566
	Sub-sample B	567–1955	28-Mar-88	1389
	Sub-sample C	1956–2289	29-Sep-93	334
	Sub-sample D	2290–3473	25-Jan-95	1184
Tin	Full sample	1000–3473	12-Dec-89	2474
	Sub-sample A	1000–1948	12-Dec-89	949
	Sub-sample B	1949–2442	20-Sep-93	494
	Sub-sample C	2443–3473	18-Aug-95	1031
Zinc	Full sample	1–3473	01-Feb-86	3473
	Sub-sample A	1–808	01-Feb-86	808
	Sub-sample B	809–1955	13-Mar-89	1147
	Sub-sample C	1956–3473	29-Sep-93	1518

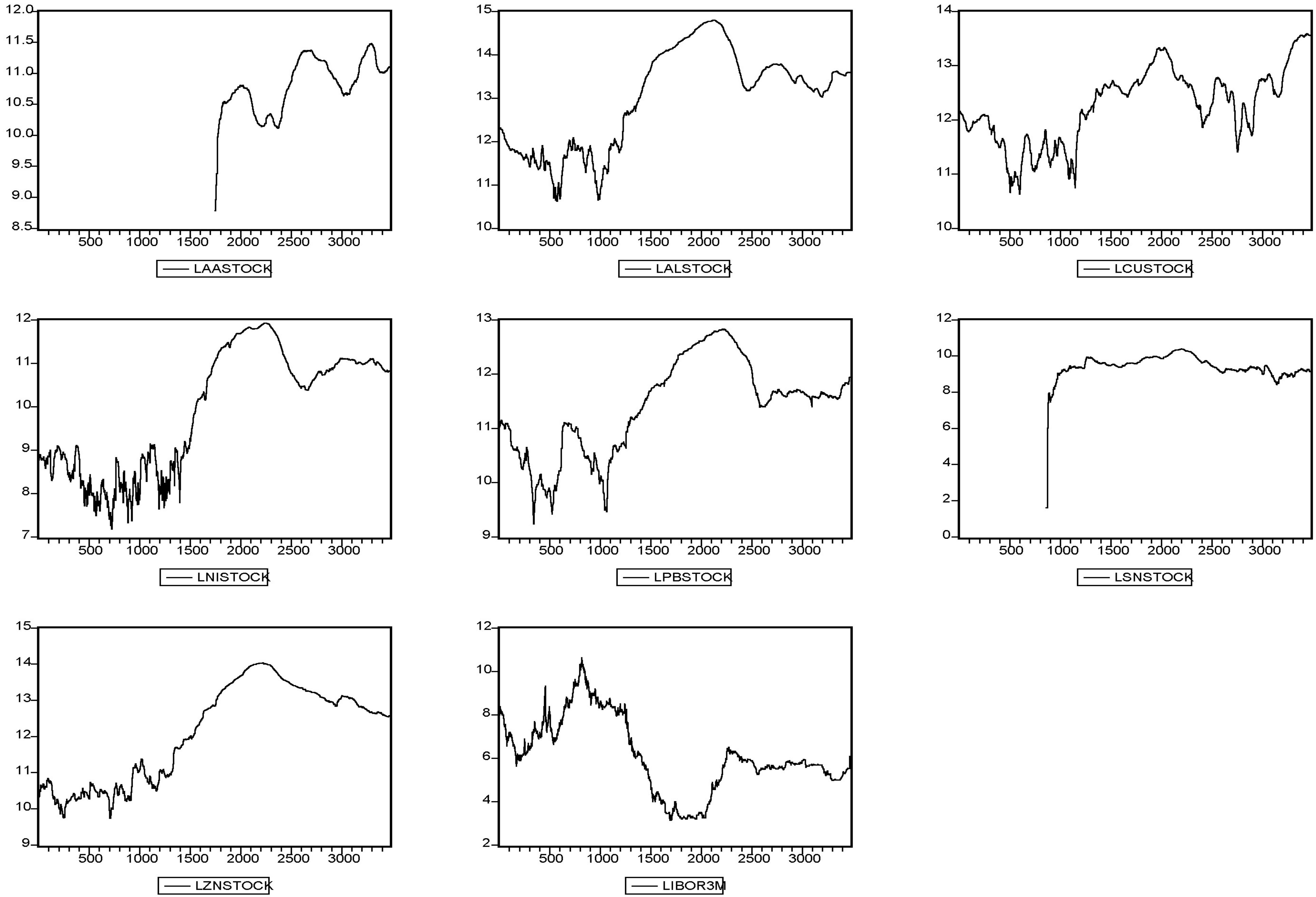
Plots of Futures Prices



Plots of Spot Prices



Plots of Stock Levels and LIBOR



Non-stationarity in the data

- We use the Augmented Dickey Fuller test (with and without a trend term) to test for unit roots in each subsample.

$$\Delta x_t = \alpha + \gamma t + \beta x_{t-1} + \sum_{i=1}^{p} \delta_i \Delta x_{t-i} + v_t \qquad (8)$$

- AIC, SBIC, HQC used to select the optimal lag length.
- Each series is I(1), within the full sample, and for the sub-samples for each metal, with the exceptions of:
  - the spot and futures prices for the aluminium sub-sample B
  - the interest rate for nickel sub-sample B
  - the spot and futures prices for the tin sub-sample C.
  - these variables appear to be I(0).

Table 2. Unit root tests for aluminium alloy

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	5	4	5	4	8	8	0	0
	Statistic	−1.833	−15.586	−1.774	−15.409	−1.477	−6.535	−1.937	−38.127
	Critical value	−3.415	−2.864	−3.415	−2.864	−3.415	−2.864	−3.415	−2.864
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	3	3	5	4	0	1
	Statistic	−3.127	−14.351	−3.187	−10.115	−1.634	−4.341	−2.254	−12.151
	Critical value	−3.423	−2.869	−3.423	−2.869	−3.423	−2.869	−3.423	−2.869
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	5	4	5	4	8	7	0	0
	Statistic	−2.591	−13.183	−2.447	−13.318	−1.541	−6.035	−0.884	−34.358
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864

Table 3. Unit root tests for aluminium

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	0	0	1	0	5	4	1	0
	Statistic	−2.461	−60.392	−2.060	−62.870	−1.134	−20.091	−1.157	−54.282
	Critical value	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	1	0	1	0	0	4	1	0
	Statistic	−1.101	−26.960	−0.741	−28.546	−2.314	−8.696	−2.745	−21.669
	Critical value	−3.419	−2.867	−3.419	−2.867	−3.419	−2.867	−3.419	−2.867
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	0	0	0	0	5	4	0	0
	Statistic	−4.910	−36.084	−3.803	−38.408	−1.648	−13.193	−3.104	−35.311
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864
C	Trend?	Y	N	Y	N	Y	Y	Y	N
	Lag length	0	2	0	2	5	4	0	1
	Statistic	−2.163	−11.982	−2.103	−11.874	−0.201	−5.270	−2.914	−10.552
	Critical value	−3.426	−2.871	−3.426	−2.871	−3.426	−3.426	−3.426	−2.871
D	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	0	0	1	0	5	4	0	0
	Statistic	−2.911	−36.580	−2.586	−36.761	−2.586	−6.294	−0.890	−34.474
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864

Table 4. Unit root tests for copper

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	N	N	N	N	Y	N	Y	N
	Lag length	2	4	5	4	5	4	1	0
	Statistic	−2.057	−25.216	−2.6	−24.910	−2.604	−15.212	−1.157	−54.282
	Critical value	−2.863	−2.863	−2.863	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	5	4	5	4	5	4	1	0
	Statistic	−2.513	−10.801	−2.140	−11.340	−2.016	−7.933	−2.654	−24.375
	Critical value	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	1	0	1	0	5	4	0	8
	Statistic	−2.886	−39.940	−2.107	−41.564	−2.693	−10.184	−1.751	−14.150
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864
C	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	0	1	0	1	5	4	0	1
	Statistic	−3.122	−15.070	−2.939	−14.722	−1.536	−4.874	−2.607	−10.834
	Critical value	−3.426	−2.871	−3.426	−2.871	−3.426	−2.871	−3.426	−2.871
D	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	2	1	1	0	6	5	0	0
	Statistic	−1.882	−27.847	−1.690	−38.660	−2.626	−6.591	−0.890	−34.474
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864

Table 5. Unit root tests for lead

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	4	3	3	2	5	4	1	0
	Statistic	−2.529	−31.752	−2.124	−40.062	−1.519	−20.137	−1.157	−54.282
	Critical value	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	4	3	3	2	5	4	1	0
	Statistic	−2.828	−17.450	−2.129	−23.353	−1.969	−11.244	−2.531	−30.189
	Critical value	−3.416	−2.865	−3.416	−2.865	−3.416	−2.865	−3.416	−2.865
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	2	1	0	0	0	0
	Statistic	−1.919	−20.249	−1.862	−25.250	−2.004	−29.314	−0.884	−27.702
	Critical value	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866
C	Trend?	Y	N	Y	N	Y	Y	Y	N
	Lag length	1	0	1	0	6	5	0	0
	Statistic	−2.865	−29.477	−2.702	−30.127	−0.842	−8.204	−0.270	−24.239
	Critical value	−3.419	−2.866	−3.419	−2.866	−3.419	−3.419	−3.419	−2.866
D	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	2	1	0	0	0	0
	Statistic	−2.961	−20.120	−2.675	−23.523	−0.890	−28.441	−0.430	−28.836
	Critical value	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865

Table 6. Unit root tests for nickel

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	0	0	1	0	0	7	1	0
	Statistic	−2.098	−58.859	−2.015	−56.636	−2.055	−23.827	−1.157	−54.282
	Critical value	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	5	5	3	2	0	0	1	0
	Statistic	3.412	−6.084	2.383	−8.022	−2.476	−23.540	−2.622	−20.531
	Critical value	−3.420	−2.867	−3.420	−2.867	−3.420	−2.867	−3.420	−2.867
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	8	3	3	2	5	5	0	0
	Statistic	−2.950	−22.431	−2.325	−24.871	−2.537	−16.960	−3.688	−35.600
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864	−3.416	−2.864
C	Trend?	Y	N	Y	N	Y	Y	Y	N
	Lag length	0	1	0	1	5	4	0	0
	Statistic	−1.518	−14.375	−1.466	−14.358	−1.000	−4.162	−2.056	−17.136
	Critical value	−3.425	−2.870	−3.425	−2.870	−3.425	−3.425	−3.425	−2.870
D	Trend?	Y	N	Y	N	Y	Y	Y	N
	Lag length	0	0	0	0	5	4	0	0
	Statistic	−1.051	−34.650	−0.996	−34.511	−3.271	−9.447	−0.890	−34.488
	Critical value	−3.416	−2.864	−3.416	−2.864	−3.416	−3.416	−3.416	−2.864

Table 7. Unit root tests for tin

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	0	2	5	4	0	0
	Statistic	−3.027	−31.659	−3.263	−31.526	−2.320	−15.857	−1.756	−47.938
	Critical value	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	3	2	5	4	0	0
	Statistic	−0.445	−20.182	−0.305	−20.049	−29.982	−10.188	−1.289	−29.982
	Critical value	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865
B	Trend?	Y	N	Y	N	Y	Y	Y	N
	Lag length	0	0	0	0	5	4	0	0
	Statistic	−3.014	−20.901	−3.071	−21.198	−0.450	−7.121	−0.068	−21.244
	Critical value	−3.421	−2.868	−3.421	−2.868	−3.421	−3.421	−3.421	−2.868
C	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	1	2	0	2	7	4	0	0
	Statistic	−4.146	−23.117	−4.363	−23.156	−2.526	−10.194	−0.584	−31.382
	Critical value	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865	−3.417	−2.865

Table 8. Unit root tests for zinc

Sample	ADF test	Spot	Δ Spot	Futures	Δ Futures	Stocks	Δ Stocks	Interest	Δ Interest
Full	Trend?	N	N	Y	N	Y	N	Y	N
	Lag length	5	2	5	4	5	4	1	0
	Statistic	−2.570	−37.240	−2.335	−25.9987	−0.453	−22.144	−1.157	−54.282
	Critical value	−2.863	−2.863	−3.414	−2.863	−3.414	−2.863	−3.414	−2.863
A	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	2	1	1	0	0	0	1	0
	Statistic	−0.812	−22.389	−0.584	−30.478	−27.848	−27.848	−2.421	−24.972
	Critical value	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866	−3.418	−2.866
B	Trend?	Y	N	Y	N	Y	N	Y	N
	Lag length	3	2	0	2	5	4	0	8
	Statistic	−2.506	−22.221	−2.379	−21.205	−2.317	−11.197	−1.710	−14.414
	Critical value	−3.416	−2.865	−3.416	−2.865	−3.416	−2.865	−3.416	−2.865
C	Trend?	Y	N	N	N	Y	N	Y	N
	Lag length	1	0	1	0	5	4	0	0
	Statistic	−2.259	−43.391	−2.323	−44.197	−3.2459	−11.478	−2.771	−37.463
	Critical value	−3.415	−2.864	−2.864	−2.864	−3.415	−2.864	−3.415	−2.864

Cointegration relationships in equation (7)

- Tests for the number of cointegrating vectors were conducted using the Johansen maximum likelihood procedure
  - with unrestricted intercept and trend term
  - for each sample where the variables were found to be I(1)
  - var lengths of 1-6 were considered, with 5 preferred
  - trace statistic is favoured over maximal eigenvalue
- Most samples are found to have one cointegrating vector.
  - Two cointegrating vectors in aluminium sample D, nickel sample D, and zinc sample C.
- Heaney (1998) shows that a strict interpretation of the cost of carry model implies that more than one cointegrating relationship between the variables is inconsistent with the cost-of-carry model.

Table 9. Cointegration tests for the general model

Market	Sample	VAR length	Maximal eigenvalue	Trace
Aluminium alloy	Full	5	1	1
	A	5	1	1
	B	5	1	1
Aluminium	Full	5	1	1
	A	5	2	1
	C	5	0	0
	D	2	3	2
Copper	Full	5	1	1
	A	5	0	1
	B	5	1	1
	C	1	1	1
	D	5	1	1
Lead	Full	5	1	1
	A	5	1	1
	B	3	2	1
	C	5	1	1
	D	3	2	1
Nickel	Full	5	1	1
	A	4	1	1
	B	5	1	1
	C	5	1	1
	D	6	1	2
Tin	Full	5	1	1
	A	5	1	1
	B	5	1	1
Zinc	Full	5	1	1
	A	4	1	1
	B	3	1	1
	C	5	2	2

Expected sign and magnitude of estimates

- Cointegrating vectors normalised on the futures price.
- Spot price coefficient should be positive and close to 1 as the spot and futures prices should trend together in the long run.
- Interest rate coefficient should be:
  - Positive under cost of carry.
  - Chow et al. (2000) show that (4) could be considered a special case of the risk premium hypothesis where the interest rate is a proxy for the premium. This interpretation implies the coefficient should be negative.
- Stock level coefficient should be negative under cost of carry.
  - Presuming convenience yield dominates risk on inventory.
- Stock level and interest rate coefficients should be relatively small in absolute magnitude (~0.05).

Table 10. Cointegrating vectors for the general model

Market	Sample	Spot	Stock	Interest	LR	Prob
Aluminium alloy	Full	1.300	0.034	−0.072	54.997	0.000
	A	0.966	0.006	0.000	49.189	0.000
	B	1.198	0.033	−0.054	19.832	0.000
Aluminium	Full	0.894	0.023	0.013	97.138	0.000
	A	0.856	0.056	−0.002	46.566	0.000
	D	0.961	0.005	0.015	–	
Copper	Full	0.982	0.040	−0.001	57.560	0.000
	A	1.207	0.175	−0.028	18.813	0.000
	B	1.075	0.011	−0.015	31.654	0.000
	C	1.010	−0.001	−0.007	25.079	0.000
	D	1.025	0.030	0.031	29.484	0.000
Lead	Full	0.987	0.031	0.000	100.751	0.000
	A	1.168	0.094	−0.010	49.997	0.000
	B	0.952	0.002	−0.002	75.870	0.000
	C	0.947	0.014	0.008	50.459	0.000
	D	1.280	0.023	0.052	10.459	0.015
Nickel	Full	0.963	0.017	0.003	56.439	0.000
	A	0.893	0.009	0.020	19.706	0.000
	B	1.070	0.008	0.007	37.779	0.000
	C	0.994	−0.024	0.002	32.616	0.000
	D	0.995	0.004	−0.001	–	
Tin	Full	0.989	0.004	0.001	28.538	0.000
	A	1.027	0.010	0.004	24.654	0.000
	B	0.865	−0.019	0.028	21.867	0.000
Zinc	Full	0.945	0.013	0.001	80.507	0.000
	A	0.942	0.045	0.003	35.938	0.000
	B	0.897	0.002	−0.001	55.560	0.000
	C	1.144	0.131	−0.078	–	

Notes: The endogenous variable is the futures price. The LR statistic is the joint test of coefficients on all the variables in the model. The degree of freedom of the LR tests is 3 in each zero

Cointegrating vector estimates for (7)

- Spot price coefficients
  - Positive and close to one for all models.
- Inventory coefficients
  - Positive for all but three models.
  - Small relative to the spot price coefficient
- Interest rate coefficients
  - Positive for 14 models, negative for 12 models, zero for 2.
  - Small relative to the spot price coefficient
- LR statistic is significant for a joint test of zero coefficients on all the endogenous variables in each model, rejecting the null hypothesis.
  - Evaluated at a 5% level of significance.

Tests of restrictions on the general model

- Likelihood ratio tests are conducted in the presence of restrictions on the general model:
  - Risk premium model (2)
    - Delete both inventory and interest rate from the model
  - Cost-of-carry model (4)
    - Delete only inventory from the model
  - Cost-of-carry model (7) excluding the interest rate
    - Delete only interest rate from the model
  - Equal inventory and interest rate coefficients in (7)
    - Not supportive of cost-of-carry
  - Opposite inventory and interest rate coefficients
    - Supports cost-of-carry if signs are correct, that is, positive for the interest rate, negative for inventory
- Test statistics were evaluated at a 5% level of significance.

Table 11. Restrictions on the general model for aluminium

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Aluminium	Full	Model (3.2)	0.913	0.000	0.000	20.034 (2)	0.000
		Model (3.4)	0.915	0.000	0.000	20.027 (1)	0.000
		No Interest Rate	0.933	0.010	0.000	12.810 (2)	0.000
		Equal	0.878	0.012	0.012	10.104 (3)	0.001
		Opposite	0.929	0.002	–0.002	18.513 (1)	0.000
	A	Model (3.2)	0.843	0.000	0.000	2.786 (2)	0.248
		Model (3.4)	0.810	0.000	0.010	1.232 (1)	0.267
		No Interest Rate	0.848	0.049	0.000	0.027 (1)	0.870
		Equal	0.814	0.009	0.009	0.862 (1)	0.353
		Opposite	0.808	–0.010	0.010	1.834 (1)	0.176
	D	Model (3.2)	1.083	0.000	0.000	68.914 (4)	0.000
		Model (3.4)	0.958	0.000	0.019	17.107 (2)	0.000
		No Interest Rate	1.041	0.013	0.000	58.612 (2)	0.000
		Equal	0.981	0.010	0.010	17.897 (2)	0.000
		Opposite	1.084	0.000	0.000	67.294 (2)	0.000

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 12. Restrictions on the general model for aluminium alloy

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Aluminium alloy	Full	Model (3.2)	0.990	0.000	0.000	27.826 (2)	0.000
		Model (3.4)	1.353	0.000	−0.095	6.406 (1)	0.011
		No Interest Rate	1.002	0.012	0.000	25.228 (1)	0.000
		Equal	1.020	−0.011	−0.011	26.329 (1)	0.000
		Opposite	1.172	0.038	−0.038	5.327 (1)	0.021
	A	Model (3.2)	0.958	0.000	0.000	0.997 (2)	0.607
		Model (3.4)	0.959	0.000	0.000	0.994 (1)	0.319
		No Interest Rate	0.965	0.006	0.000	0.003 (1)	0.960
		Equal	0.957	0.002	0.002	0.741 (1)	0.389
		Opposite	0.965	0.002	−0.002	0.638 (1)	0.424
	B	Model (3.2)	0.952	0.000	0.000	11.504 (2)	0.003
		Model (3.4)	1.101	0.000	−0.060	3.854 (1)	0.050
		No Interest Rate	1.189	0.056	0.000	5.941 (1)	0.015
		Equal	0.944	−0.004	−0.004	11.430 (1)	0.001
		Opposite	1.213	0.043	−0.043	0.431 (1)	0.512

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 13. Restrictions on the general model for copper

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Copper	Full	Model (3.2)	0.946	0.000	0.000	20.490 (2)	0.000
		Model (3.4)	0.963	0.000	−0.009	12.730 (1)	0.000
		No Interest Rate	0.982	0.041	0.000	0.068 (1)	0.794
		Equal	0.953	−0.007	−0.007	17.182 (1)	0.000
		Opposite	0.970	0.009	−0.009	8.920 (1)	0.003
	A	Model (3.2)	0.878	0.000	0.000	14.910 (2)	0.001
		Model (3.4)	0.700	0.000	0.039	8.670 (1)	0.003
		No Interest Rate	1.015	0.111	0.000	1.421 (1)	0.233
		Equal	0.790	0.028	0.028	7.082 (1)	0.008
		Opposite	0.349	−0.088	0.088	8.964 (1)	0.003
	B	Model (3.2)	1.156	0.000	0.000	4.421 (2)	0.110
		Model (3.4)	1.067	0.000	−0.016	0.700 (1)	0.403
		No Interest Rate	1.158	0.019	0.000	3.306 (1)	0.069
		Equal	1.096	−0.010	−0.010	3.038 (1)	0.081
		Opposite	1.079	0.014	−0.014	0.043 (1)	0.836
	C	Model (3.2)	1.014	0.000	0.000	1.839 (2)	0.399
		Model (3.4)	1.012	0.000	−0.006	0.009 (1)	0.926
		No Interest Rate	1.019	0.004	0.000	1.778 (1)	0.182
		Equal	1.003	−0.006	−0.006	0.163 (1)	0.686
		Opposite	1.020	0.005	−0.005	0.256 (1)	0.613
	D	Model (3.2)	1.097	0.000	0.000	8.989 (2)	0.011
		Model (3.4)	1.082	0.000	0.008	8.878 (1)	0.003
		No Interest Rate	1.803	0.026	0.000	3.556 (1)	0.059
		Equal	1.027	0.030	0.030	0.006 (1)	0.937
		Opposite	1.116	0.014	−0.014	6.771 (1)	0.009

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 14. Restrictions on the general model for lead

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Lead	Full	Model (3.2)	0.947	0.000	0.000	35.144 (2)	0.000
		Model (3.4)	0.994	0.000	−0.011	24.594 (1)	0.000
		No Interest Rate	0.986	0.031	0.000	0.017 (1)	0.896
		Equal	0.957	−0.003	−0.003	34.540 (1)	0.000
		Opposite	1.005	0.010	−0.010	14.649 (1)	0.000
	A	Model (3.2)	1.026	0.000	0.000	23.414 (2)	0.000
		Model (3.4)	1.024	0.000	0.008	22.879 (1)	0.000
		No Interest Rate	1.150	0.083	0.000	1.291 (1)	0.256
		Equal	1.052	0.018	0.018	17.995 (1)	0.000
		Opposite	1.066	0.021	−0.021	20.967 (1)	0.000
	B	Model (3.2)	0.954	0.000	0.000	2.418 (2)	0.298
		Model (3.4)	0.951	0.000	−0.002	0.013 (1)	0.911
		No Interest Rate	0.959	0.015	0.000	0.576 (1)	0.448
		Equal	0.950	−0.003	−0.003	0.061 (1)	0.805
		Opposite	0.952	0.002	−0.002	0.000 (1)	0.996
	C	Model (3.2)	0.983	0.000	0.000	26.802 (2)	0.000
		Model (3.4)	0.945	0.000	0.013	1.390 (1)	0.238
		No Interest Rate	0.952	0.032	0.000	2.853 (1)	0.091
		Equal	0.946	0.009	0.009	0.166 (1)	0.684
		Opposite	0.946	−0.018	0.018	6.451 (1)	0.011
	D	Model (3.2)	1.720	0.000	0.000	8.385 (2)	0.015
		Model (3.4)	1.311	0.000	0.059	0.205 (1)	0.650
		No Interest Rate	1.339	0.088	0.000	6.925 (1)	0.009
		Equal	1.254	0.045	0.045	0.253 (1)	0.615
		Opposite	1.441	−0.069	0.069	2.395 (1)	0.122

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 15. Restrictions on the general model for nickel

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Nickel	Full	Model (3.2)	0.951	0.000	0.000	8.359 (3)	0.015
		Model (3.4)	0.960	0.000	–0.004	6.265 (1)	0.012
		No Interest Rate	0.966	0.014	0.000	0.443 (1)	0.505
		Equal	0.950	0.001	0.001	8.329 (1)	0.004
		Opposite	0.964	0.004	–0.004	3.985 (1)	0.046
	A	Model (3.2)	0.945	0.000	0.000	8.977 (2)	0.011
		Model (3.4)	0.890	0.000	0.019	0.311 (1)	0.577
		No Interest Rate	0.931	–0.017	0.000	8.489 (1)	0.004
		Equal	0.902	0.020	0.020	0.671 (1)	0.413
		Opposite	0.889	–0.015	0.015	2.242 (1)	0.134
	B	Model (3.2)	1.071	0.000	0.000	1.109 (2)	0.574
		Model (3.4)	1.069	0.000	0.006	0.404 (1)	0.525
		No Interest Rate	1.072	0.006	0.000	0.930 (1)	0.335
		Equal	1.070	0.007	0.007	0.007 (1)	0.932
		Opposite	1.070	–0.003	0.003	0.881 (1)	0.348
	C	Model (3.2)	0.988	0.000	0.000	17.399 (1)	0.000
		Model (3.4)	0.993	0.000	0.004	9.873 (1)	0.002
		No Interest Rate	0.993	–0.030	0.000	8.667 (1)	0.003
		Equal	0.992	0.004	0.004	11.777 (1)	0.001
		Opposite	0.993	–0.004	0.004	7.982 (1)	0.005
	D	Model (3.2)	0.993	0.000	0.000	4.498 (4)	0.343
		Model (3.4)	0.993	0.000	0.002	3.137 (2)	0.208
		No Interest Rate	0.995	0.003	0.000	0.140 (2)	0.932
		Equal	0.994	0.002	0.002	1.275 (2)	0.529
		Opposite	0.995	0.003	–0.003	2.854 (2)	0.240

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 16. Restrictions on the general model for tin

Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Tin	Full	Model (3.2)	0.992	0.000	0.000	1.551 (2)	0.460
		Model (3.4)	0.985	0.000	0.001	0.675 (1)	0.411
		No Interest Rate	0.996	0.002	0.000	1.303 (1)	0.254
		Equal	0.985	0.001	0.001	0.357 (1)	0.550
		Opposite	0.985	−0.001	0.001	0.972 (1)	0.324
	A	Model (3.2)	1.005	0.000	0.000	5.024 (2)	0.081
		Model (3.4)	1.026	0.000	0.006	1.195 (1)	0.274
		No Interest Rate	1.014	0.013	0.000	2.625 (1)	0.105
		Equal	1.028	0.005	0.005	0.300 (1)	0.548
		Opposite	1.021	−0.005	0.005	2.644 (1)	0.104
	B	Model (3.2)	0.475	0.000	0.000	21.554 (2)	0.000
		Model (3.4)	0.896	0.000	0.018	2.196 (1)	0.138
		No Interest Rate	0.366	−0.007	0.000	21.545 (1)	0.000
		Equal	0.902	0.011	0.011	8.685 (1)	0.003
		Opposite	0.826	−0.036	0.036	0.590 (1)	0.442

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 17. Restrictions on the general model for zinc

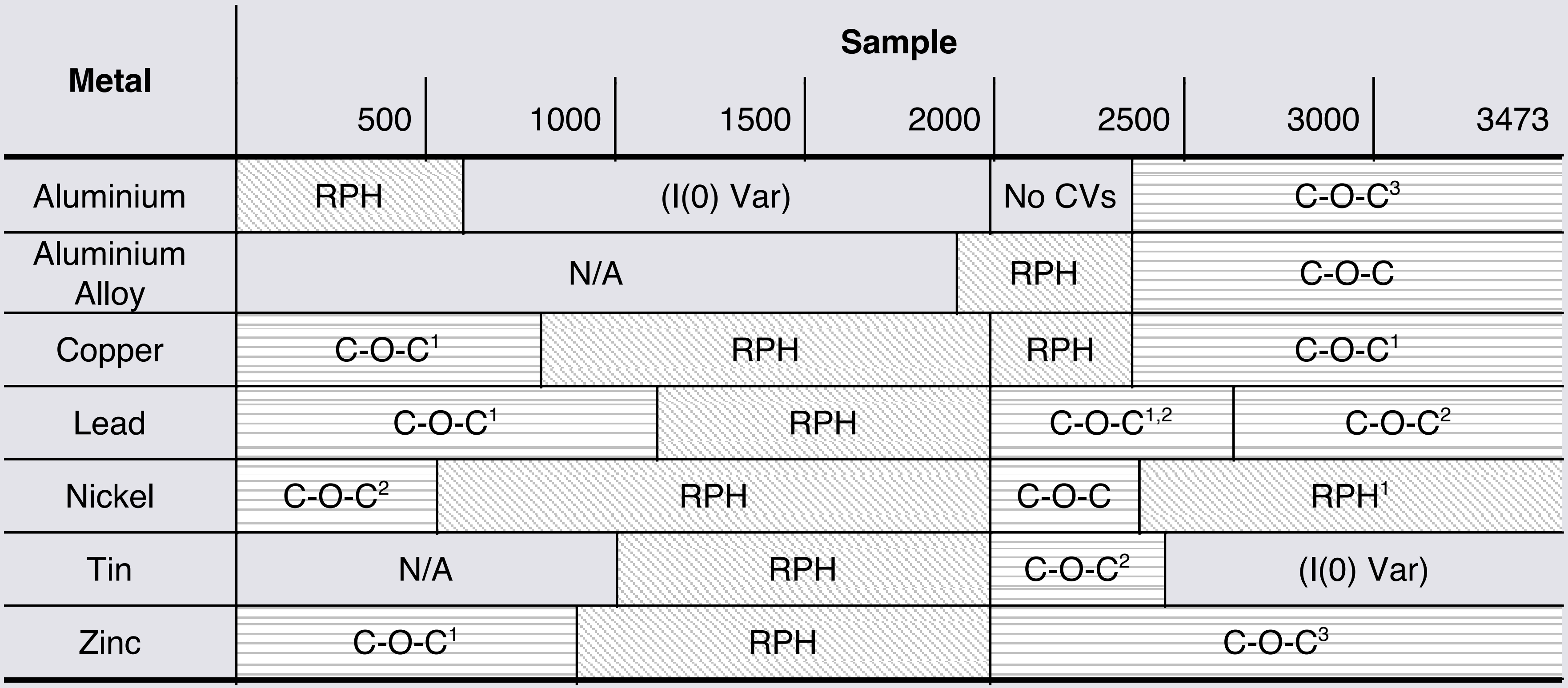
Market	Sample	Restrictions	Spot	Stock	Interest	LR	Prob
Zinc	Full	Model (3.2)	0.938	0.000	0.000	13.674 (2)	0.000
		Model (3.4)	0.952	0.000	−0.004	9.964 (1)	0.002
		No Interest Rate	0.948	0.012	0.000	0.239 (1)	0.625
		Equal	0.936	0.001	0.001	13.591 (1)	0.000
		Opposite	0.955	0.004	−0.004	5.725 (1)	0.017
	A	Model (3.2)	0.947	0.000	0.000	13.086 (2)	0.001
		Model (3.4)	0.923	0.000	0.011	8.515 (1)	0.004
		No Interest Rate	0.947	0.049	0.000	0.443 (1)	0.506
		Equal	0.925	0.011	0.011	6.126 (1)	0.013
		Opposite	0.926	−0.010	0.010	10.985 (1)	0.001
	B	Model (3.2)	0.899	0.000	0.000	0.120 (2)	0.942
		Model (3.4)	0.897	0.000	−0.002	0.050 (1)	0.822
		No Interest Rate	0.898	0.003	0.000	0.030 (1)	0.862
		Equal	0.898	−0.001	−0.001	0.114 (1)	0.736
		Opposite	0.897	0.002	−0.002	0.008 (1)	0.930
	C	Model (3.2)	0.899	0.000	0.000	57.453 (4)	0.000
		Model (3.4)	1.067	0.000	−0.055	7.683 (2)	0.021
		No Interest Rate	0.898	−0.011	0.000	46.039 (2)	0.000
		Equal	1.006	−0.036	−0.036	14.718 (2)	0.001
		Opposite	1.132	0.076	−0.076	1.584 (2)	0.461

Notes: The endogenous variable is the futures price. The LR statistic tests the validity of zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

Table 18. Inference summary

Market	Full sample	Sample A	Sample B	Sample C	Sample D
Aluminium alloy	C–O–C	RPH	C–O–C	–	–
Aluminium	C–O–C	RPH	(I(0) Var)	(No CVs)	C–O–C[3]
Copper	C–O–C[1]	C–O–C[1]	RPH	RPH	C–O–C[1]
Lead	C–O–C[1]	C–O–C[1]	RPH	C–O–C[1]	C–O–C[2]
Nickel	C–O–C[1]	C–O–C[2]	RPH	C–O–C	RPH[1]
Tin	RPH	RPH	C–O–C[2]	(I(0) Var)	–
Zinc	C–O–C[1]	C–O–C[1]	RPH	C–O–C[3]	–

C–O–C[1] denotes that the no-interest rate model was not rejected. C–O–C[2] denotes the cost-of-carry model in equation (3.4) was not rejected. Where C–O–C[3] and RPH[1] appear, there exist 2 significant cointegrating vectors. For all models listed as C–O–C, the model in equation (3.2) was rejected.



Conclusion

- A version of the cost-of-carry model holds over the full sample for all metals except tin, for which the risk premium model is preferred.
  - Positive stock level coefficient is problematic for (7)
  - Negative interest rate coefficient is problematic for (4) and (7) in some instances, however the magnitude is typically small, and the interest rate can be excluded from copper, lead nickel and zinc.

Conclusion

- When looking at the sub-samples, the risk premium hypothesis is rejected less frequently.
- The cost-of-carry model applies to 12 sub-samples
  - The interest rate may be excluded from four of these
  - The inventory variable may be excluded from three
  - The interest rate an inventory may be individually but not jointly excluded from one model
- It would appear that the risk premium hypothesis may be supported during periods of long down-trends in metals prices.
  - This is intuitive to the extend that inventories may be less important during periods of long price declines that are associated with loose metals balances