Pricing of Non-ferrous Metals Futures on the London Metal Exchange

Clinton Watkins and Michael McAleer

Department of Economics

University of Western Australia

January 2003

Abstract: The London Metal Exchange (LME) is the most important centre for spot and futures trading in the main industrially-used non-ferrous metals. In this paper, data on 3-month futures contracts for aluminium, aluminium alloy, copper, lead, nickel, tin and zinc are analysed. The risk premium hypothesis and the cost-of-carry model are the standard theoretical models for pricing futures contracts, but these two models have rarely been estimated within a unified framework for metals futures. Single equation versions of the risk premium hypothesis and the cost-of-carry model are nested within a more general model. If the spot price, futures price, interest rate and stock level variables contain stochastic trends, long run versions of the general model can be estimated within a cointegration framework. Various long run pricing models are estimated using daily LME price data for the period 1 February 1986 to 30 September 1998. Likelihood ratio tests are used to test restrictions on the general model to examine the validity of alternative nested specifications.

Corresponding Author:

Michael McAleer

Department of Economics	Telephone:	+618 9380 3400
University of Western Australia	Facsimile:	+618 9380 1016
35 Stirling Highway	Email:	Michael.McAleer@uwa.edu.au
Crawley, WA 6009		
AUSTRALIA		

1 Introduction

The London Metal Exchange (LME) is the major international market for the main industrially-used non-ferrous metals, namely aluminium, aluminium alloy, copper, lead, nickel, tin, zinc and silver. It is used worldwide by producers and consumers of non-ferrous metals as a centre for spot, futures and options trading in these metals. Three primary functions are performed by the non-ferrous metals markets on the LME. First, the exchange provides a market where non-ferrous metal industry participants can hedge against risks arising from price fluctuations in world metals markets. Second, settlement prices determined on the LME are used internationally as reference prices for the valuation of activities relating to non-ferrous metals. Third, the LME also provides appropriately located storage facilities to enable market participants to take or make physical delivery of approved brands of non-ferrous metals. The LME is the most important market for pricing of non-ferrous metals world wide. Approximately 95% of the total world trade in copper futures occurs though the LME, with the bulk of the remaining 5% in the copper market on the Commodity Exchange of New York (COMEX). Smaller regional markets typically participate only in spot trade of non-ferrous metals. One exception is the Shanghai Futures Exchange (SHFE), on which a small volume of futures for aluminium and copper are traded primarily for the Chinese domestic market. The copper settlement price determined on the LME is effectively the world copper price [Gilbert, 1996].

This paper applies econometric time series techniques to LME futures and spot price data, and estimates long run pricing models for non-ferrous metals futures contracts. A more accurate view of futures prices for metals is of particular interest to participants in industries reliant on the production or consumption of metals, such as miners, smelters, refiners, rolling mills, extrusion plants, metals merchants, and fabricators. Energy providers, banks, investment funds and, to some extent, speculators, are also active participants in metals futures markets. At a macroeconomic level, commodity prices play an important role in the economy of many countries, including Australia. Developing economies are particularly reliant on commodity production in the generation of national income. A greater understanding of the relationship between futures and spot prices has important policy implications for commodity-dependent nations for key indicators such as exchange rates, inflation and economic growth.

The plan of the paper is as follows. Section 2 examines previous empirical work on pricing and efficiency aspects of non-ferrous metals futures markets. Issues pertaining to the modelling of long run relationships using cointegration are discussed in Section 3. Futures pricing models are examined in Section 4. The data used are described in Section 5. Tests for non-stationarity are discussed in Section 6. Section 7 presents tests for cointegration and estimates of the long run pricing models. Some concluding comments are given in Section 8.

2 Previous Studies of Non-ferrous Metals Spot and Futures Pricing

Several recently published empirical papers analyse aspects of spot and futures pricing for non-ferrous metals, with the majority focusing on the LME. Non-ferrous metals markets, including those for aluminium, aluminium alloy, copper, lead, nickel, tin and zinc, are frequently the subject of empirical analysis. Properties of precious metals markets, namely gold, silver, platinum and palladium, have also been investigated. Empirical research involving non-ferrous metals spot and futures markets can be classified into four broad areas: market efficiency; the theory of storage and cost-of-carry model; price volatility and risk; and other aspects of metals markets.

Much of the non-ferrous metals futures market empirical research published over the last two decades relates to the efficient market hypothesis. Approaches to market efficiency in non-ferrous metals markets include models of the unbiased expectations hypothesis, for example see Hsieh and Kulatilaka [1982] and Canarella and Pollard [1986]. Goss [1983] and Sephton and Cochrane [1990] investigate the properties of price forecast errors. Tests of restrictions imposed on regression models by the efficient market hypothesis are conducted in MacDonald and Taylor [1988a]. Several papers model and test the existence of time-varying risk premia (see, for example, Hall and Taylor [1989], MacDonald and Taylor [1989], Hall [1991], and Sephton and Cochrane [1991]). Efficiency motivated tests for cointegration between price series are discussed in MacDonald and Taylor [1988b], Chowdhury [1991], Fraser and MacDonald [1992], Krehbiel and Adkins [1993], Beck [1994], and Moore and Cullen [1995]. The nature of flow parities between metals prices are investigated using cointegration by Franses and Kofman [1991]. Evidence on the efficiency of the LME non-ferrous metals futures markets provided by cointegration models is mixed. Some studies support the efficient market hypothesis, while others contradict these results by rejecting efficiency for metals futures markets.

Implications of the theory of storage, and the related cost-of-carry model, for non-ferrous metals futures have been examined through modelling of the convenience yield in Fama and French [1988], the convenience yield and dispersion premium in Larson [1994], the analysis of inventory and excess demand effects on the futures basis by Choksi [1984] and Ng and Pirrong [1994], and cointegration modelling of the cost-of-carry relationship for LME lead futures (see Heaney [1998]). Tests on several non-ferrous metals support the proposition in Fama and French [1988] that the marginal convenience yield on inventory declines at higher levels of inventory, but at a decreasing rate. Evidence to support the cost-of-carry model in explaining 3-month LME lead futures prices was presented in Heaney [1998].

Empirical studies of price volatility and risk in non-ferrous metals markets include modelling the volatility of spot and futures prices using a random walk model, or various GARCH processes, and the analysis of the risk to return relationship in futures markets using a CAPM approach. Volatility of six LME spot markets has been analysed in Brunetti and Gilbert [1995], and modelled using a FIGARCH process in Teyssiere, Gilbert and Brunetti [1997]. All six metals were found to have similar volatility processes. Increased speculative activity over a long sample period does not appear to have led to increased volatility. COMEX copper futures price volatility is examined by Bracker and Smith [1999] using various GARCH specifications, in which GARCH and EGARCH were found to be superior to the GJR model, AGARCH model and a random walk model. Both AGARCH and GJR allow large negative shocks to have a greater effect on the conditional variance than large positive shocks, but the specification of the conditional variance in each model is different. The GJR model allows shocks to have a greater asymmetric effect than does AGARCH. A CAPM approach to analysing risk in non-ferrous metals futures markets by Chang, Chen and Chen [1990] found returns commensurate with the systematic risks in each market.

Other aspects of non-ferrous metals markets analysed recently include the relationship between margin requirements and market participation in Hardouvelis and Kim [1995], lead-lag relationships between copper futures markets in Shyy and Butcher [1994], and manipulation of the copper futures market on the LME analysed by Gilbert [1996].

Many of the models presented in the empirical literature are far from adequate, especially in terms of recent developments in the analysis of non-stationary processes, diagnostic testing, and testing alternative nested and non-nested models. Until recently, unit roots were typically ignored, even though it is generally acknowledged that futures price series are frequently non-stationary. In such circumstances, standard statistical techniques such as ordinary least squares should not be used because the asymptotic distributions of the estimators are non-standard. In the case of non-stationary data, ordinary least squares can produce spurious results. To date, there have been no applications of nested and non-nested tests of the cost-of-carry and risk premium models in the literature on LME futures markets. There are few empirical analyses of the cost-of-carry model. Analyses of the risk premium hypothesis generally consist of attempts to find evidence of a risk premium, rather than the specification and estimation of the model. There have also been few published metals futures market applications of either nested or non-nested tests of the various models, either in a single equation or a systems context.

3 Modelling of Long Run Relationships Using Cointegration

It is now well established that many financial time series contain a stochastic trend, that is, the series are non-stationary. Commodity spot and futures price series are no exception. Non-stationarity effects the modelling of economic relationships in that standard statistical techniques that assume stationarity yield invalid inferences in the presence of stochastic trends. Such a problem with standard regression techniques was not recognised until the 1980s. Subsequently, several papers have provided evidence for the existence of unit roots in a variety of commodity price series. However, in spite of this body of evidence, empirical researchers have frequently ignored non-stationarity, thereby drawing invalid inferences based on inappropriate asymptotic distributions, even into the 1990s. Moreover, much of the theoretical literature related to futures contract pricing does not accommodate the time series properties of the data, particularly the existence of stochastic trends (see Chow et al. [2000]).

The theory of cointegration was developed by Engle and Granger [1987]. Their error correction technique provided a method by which long run relationships among nonstationary series could be modelled. Subsequently, Johansen [1988, 1991, 1995] developed a method for estimating and testing for cointegrating relationships within a vector autoregressive framework. Given these developments in econometric theory, it is possible to estimate and test for cointegrating relationships among price variables where there is reason to believe one or more long run relationships might exist. Several empirical studies in finance have examined futures markets for various commodities and financial assets.

An agent who is buying or selling a contract in the futures market for a commodity undertakes to receive or deliver the commodity at a certain time in the future, based on a price determined today. In this context, it is reasonable to expect that a long run price relationship between the futures contract price and the underlying commodity spot price exists (see Chow et al. [2000]). Furthermore, Brenner and Kroner [1995] argue that no-arbitrage pricing formulae, such as that underlying the cost-of-carry model, result in cointegrating relationships among price variables.

The Johansen [1991] approach is used to model the long run futures pricing relationship in this paper. Inference using the Johansen procedure involves several decisions which may be based on both statistical properties of the data and economic theory. Doornik, Hendry and Nielson [1999] address several important issues of inference in the empirical application of multivariate cointegration analysis, while focusing on determining the rank of a linear dynamic system for economic time series. The large number of choices that have to be made by applied researchers in determining the specification of a cointegrating VAR model is highlighted in Pesaran and Smith [1999]. The importance of judgment and economic theory to supplement the statistical information is emphasised in the discussion of practical issues including the specification of intercepts and trends, the size of the VAR model, and the use of exogenous variables. Statistical information gleaned from the modelling process is not informative with respect to many of the choices that must be made in cointegration analysis.

4 Models of Futures Prices

This paper models the relationship between futures and spot prices. There are two popular theories for the pricing of futures contracts from which to motivate a relationship between futures and spot prices, namely the risk premium hypothesis and the theory of storage.

The risk premium hypothesis presumes the risk and return relationship commonly proposed for other asset markets is applicable to futures markets. It states that, under market efficiency and rational expectations, the futures price is equal to the expected spot price plus a risk premium. The risk premium hypothesis can be represented as:

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

where $f_{t+k|t}$ is the k-period (logarithmic) futures price at time t, conditional on information available at time t, $E_t(s_{t+k})$ is the expectation at time t of the (logarithmic) spot price at time t+k, conditional on information available at time t, and $\pi_{t+k|t}$ is the expected risk premium at time t for a futures contract maturing at t+k, given information at time t. Setting k=1 and assuming expectations are rational, an estimable form of the risk premium model can be specified as:

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

where f_t is the (logarithmic) futures price at t for a contract maturing in t+1, s_{t+1} is the (logarithmic) spot price in period t+1, and ε_t is a white noise error term. However, the expected risk premium, π_t, is frequently not a measurable or observable variable.

The cost-of-carry model (COC) uses a no-arbitrage argument by factoring in the carrying costs involved in holding an underlying asset until maturity. For commodity futures contracts, the underlying asset is the physical commodity. Carrying costs within models of commodity futures pricing include interest costs, a risk premium for holding stocks, and storage costs net of convenience yield. Convenience yield is the return due to holding inventory or stocks. This return accrues to an agent or firm because holding stocks of a commodity may reduce transactions costs involved with frequent deliveries of an input in a firm's production process, or may provide the flexibility to meet unexpected demand. The cost-of-carry argument justifies the futures price as being equal to the current spot price minus net carrying costs, and the model can be written as:

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

where r_t is the risk-free interest rate, c_t refers to storage costs net of the convenience yield, and θ_t is the marking-to-market term.

The marking-to-market term represents the process by which, at the end of each trading day, the daily gain or loss from holding a futures contract is transferred between traders. LME contracts were not marked-to-market until 1996, and prior to this daily profits and losses from holding a contract on the LME accumulated until the contract maturity date. In empirical studies the marking-to-market term is generally argued to have little realistic impact, and is expected to be stationary. For these reasons, it is zero in this model. With the marking-to-market term, θ_t, set to zero, an estimable version of the model for LME futures contracts can be represented as:

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

where ϕ_t is a white noise error term. However, the storage cost net of convenience yield is not an observable variable. An alternative specification of the cost-of-carry model is:

$$f_t = s_t + r_t + w_t + l_t, \tag{5}$$

where w_t represents storage costs over the period t to t+1, and l_t refers to stock level effects which include convenience yield and a premium for the risk due to holding stocks.

Stock level effects, l_t, have been modelled by Heaney [1998] for the LME lead market, and the same specification is used in equation (6):

$$l_t = \delta i_t - \gamma , \tag{6}$$

where i_t is the log of the inventory or stock level, and γ is a constant parameter of the model. The restriction on the parameter of the stock level, $\delta>0$, ensures the model is consistent with the behaviour of the convenience yield and risk premium effect in Working [1949]. Storage costs in equation (5), w_t, are assumed to be constant, as is consistent with the recent literature. Thus, for empirical modelling, the cost-of-carry model can be specified as:

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

where ν_t is a zero mean stationary error term.

Chow et al. [2000] note that much of the theoretical futures pricing literature does not accommodate common time series properties of financial data, particularly the existence of stochastic trends, or unit roots in the price levels. In addition, cointegration provides a linear framework in which the cost-of-carry and risk premium relationships may be directly tested when the interest rate, stock and price levels contain stochastic trends. A stationary variable can be omitted from a cointegrating regression without affecting the consistency of the coefficient estimates or the power of the statistical procedures for hypothesis testing [Park and Phillips, 1989]. Storage cost, convenience yield and risk premium variables have been traditionally considered as covariance stationary in the recent literature [Chow et al., 2000], although there have been some arguments advanced for a non-stationary convenience yield.

In the context of cointegration modelling, it is appropriate to note that long-run versions of the risk premium hypothesis and cost-of-carry models are being tested. A cointegrating vector of (1,-1) between the spot and futures prices implies that the spot price and futures price trend together in the long run but may deviate in the short run. As the long run relationship is being examined, the risk premium hypothesis, which is stated in terms of the current period futures price (f_t) and the following period's spot price (s_{t+1}), may also be specified for this purpose as a cointegrating vector between the current futures (f_t) and the current spot price (s_t).

In an application similar to that considered in this paper, Zivot [2000] examined the cointegration between forward and spot prices in relation to the forward rate unbiasedness hypothesis (FRUH) for exchange rate data. Simple models of cointegration between the current futures price (f_t) and current spot price (s_t) capture more easily the stylised facts of typical exchange rate data than simple models of cointegration between the current futures price (f_t) and the following period's spot price (s_{t+1}). Furthermore, their analysis concludes that simple models of cointegration between f_t and s_t imply complicated models of cointegration between f_t and s_{t+1}. An analogy between this approach to the FRUH for exchange rates and the RPH for commodities can be made. In the context of modelling a long-run relationship for the risk premium hypothesis, the model in equation (2) may be expressed in terms of s_t rather than s_{t+1}.

Under the above assumptions, the models in equations (2) and (4) can be considered nested within the model in equation (7). The empirical analysis will consider these three models. In each model, the spot price effect on the futures price is expected to be positive and close to one. The theory of storage implies that the effect of the interest rate in equations (4) and (7), as a cost of storage, should also be positive.

5 Data

The sample consists of daily data for the LME spot prices and 3-month contract settlement prices for aluminium, aluminium alloy, copper, lead, nickel, tin, and zinc. Table 1 shows the data used for each metal. A sample of 3473 observations, beginning 1 February 1986, was used for aluminium, copper, lead, nickel, and zinc. Trading in aluminium alloy futures contracts commenced in 1992, and the 1990 observations used commence on 16 November 1993. Contracts in tin were suspended in November 1985 and trading recommenced in July 1989. The sample for tin contains 2474 observations, beginning on 12 December 1989. Samples for each metal end on 30 September 1999. A silver contract has recently been introduced to the Exchange, but only 102 observations are available. Silver is, therefore, excluded from the analysis.

Table 1 also indicates sub-samples for each market based on apparent structural breaks evident in the spot and futures price series. The rationale for modelling based on these sub-samples is discussed later in this section and also in Section 6.

Data covering the period 3 January 1989 to 30 September 1998 are obtained from the LME. Observations prior to 3 January are from the data used in Brunetti and Gilbert [1996] compiled from the World Bureau of Metal Statistics, *World Metal Statistics*. Prices quoted for LME metals prior to

July 1993 are denominated in British Pounds. These spot and 3-month futures prices are converted from British Pounds to US Dollars using the spot and 3-month US Dollar to British Pound exchange rates, respectively. After July 1993, prices are quoted in US Dollars. LME spot and futures prices are expressed in natural logarithms, as are the stock level variables. The risk-free interest rate is expressed in levels.

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 the LME futures price series are given in the lower panels of each of Figures 1, 3, 5, 7, 9, 11 and 13, and first differences of the data are shown in the upper panel. Spot price series and their first differences are provided in Figures 2, 4, 6, 8, 10, 12 and 14. Each of the spot and futures price series exhibit several structural breaks, with the breaks in each series coinciding on approximately the same observation for a given metal. It is clear from the differenced series that there is a substantial amount of volatility in both the spot and futures markets for each metal.

Figure 1 shows the logarithm of aluminium futures prices in the lower panel and the first difference of logarithmic aluminium futures prices in the upper panel. Structural break points are evident in the log price series at observations 625 (22 June 1988), 1990 (16 November 1993), and 2290 (25 January 1995). Distinct periods of increasing and decreasing trend are clear in the log price series. For example, the first difference series does not contain a trend over time, but the volatility of the first differences changes over time. The price series follows an upward trend between 1 February 1986 and 22 June 1989, after which a long downward trend takes over until 16 November 1993. Beyond the second break point, an upward trend occurs until 25 January 1995, after which the series trends downward until the end of the sample. Volatility in the first difference of the log price series is noticeable at each structural break point. The structural breaks give rise to four sub-samples for modelling long run pricing models, when taking into account structural change.

LME spot prices for aluminium are shown in Figure 2, with the log of the price level in the lower panel and first differences of the log spot price in the upper panel. In levels and in first differences, the spot price of aluminium shares many of the characteristics of the futures price time series. Trends in the levels of each series are similar, and structural break points occur at the same time in both spot and futures price series. Similar periods of higher volatility and clusters of volatility are indicated by both first difference series. Outlying observations typically appear at the same point in time in both first difference series. Some of the outlying observations in the spot price first differences are more extreme in magnitude than are corresponding observations in the futures first differences. Spot prices cover a greater range than do the futures prices.

The aluminium alloy series begins in 1992, at observation numbered 1700 (as shown in Figure 3). To preclude the first year of the futures contract's operation, the data used in this analysis begin on 16 November 1993, or observation 1990. The behaviour of aluminium alloy futures prices appear closely related with those of aluminium, with an obvious break point at 27 January 1995 (observation 2292), two trading days after a similar structural change in the aluminium market.

Prior to observation 2292, the alloy price was trending upward, and after 27 January, prices follow a decreasing trend over several years. First differences of the aluminium alloy price are more volatile around the break point, and a large extreme negative observation occurs just after the structural break. However, volatility in alloy market first differences is at a lower extent than in the aluminium market. One reason for this is that alloy is a thinly traded market relative to aluminium. Two sub-samples are used to model long run pricing in the aluminium alloy market.

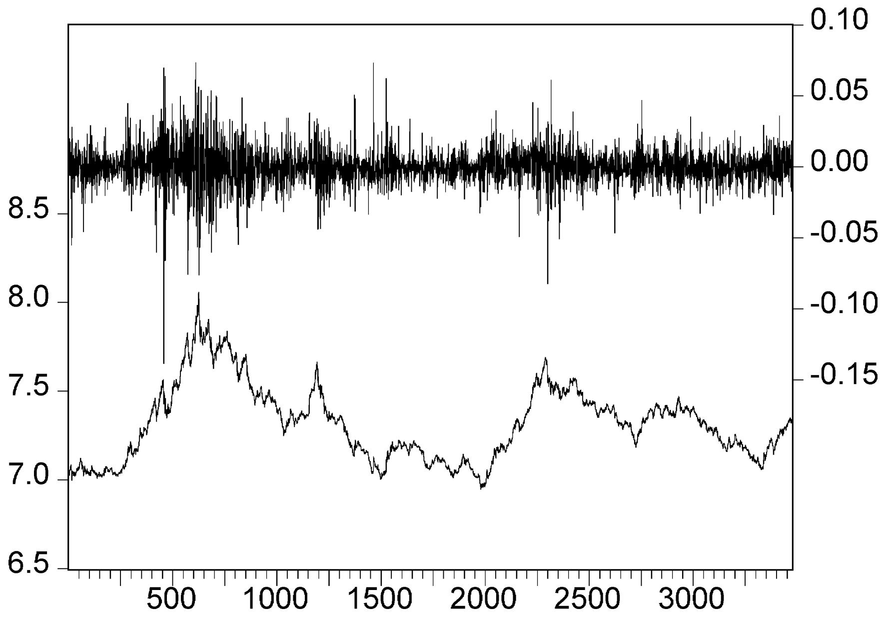

Figure 1: Logarithm of aluminium 3-month futures price (bottom) and first difference (top)

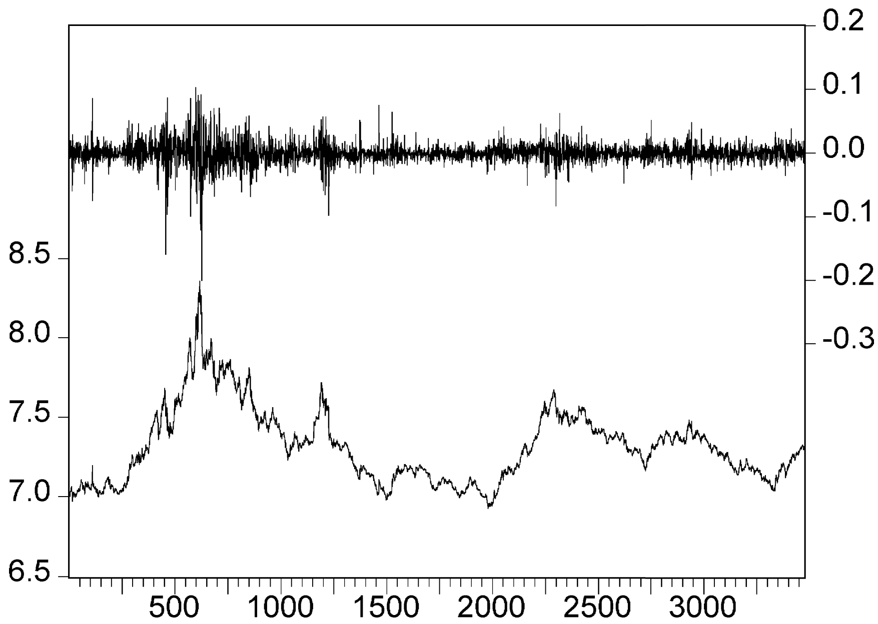

Figure 2: Logarithm of aluminium spot price (bottom) and first difference (top)

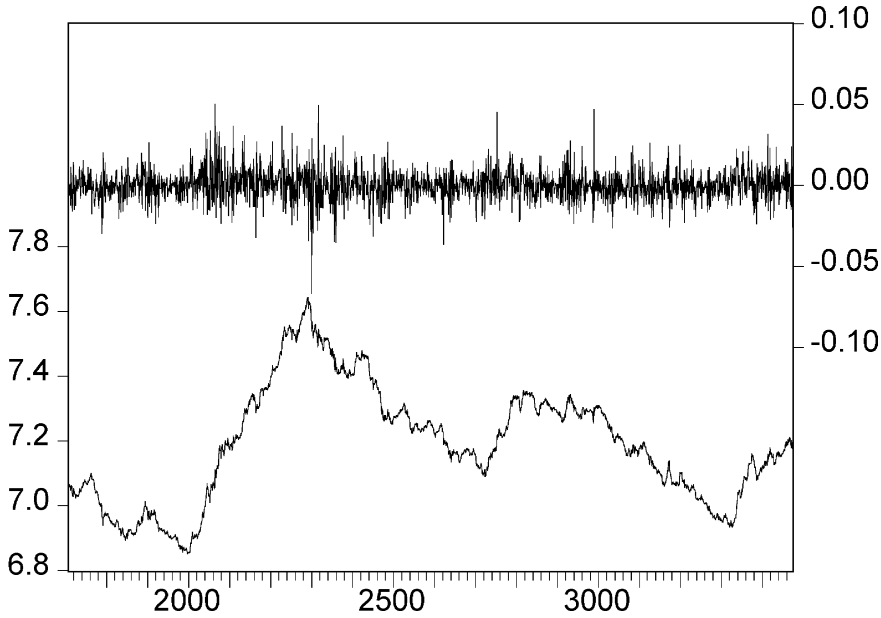

Figure 3: Logarithm of aluminium alloy 3-month futures price (bottom) and first difference (top)

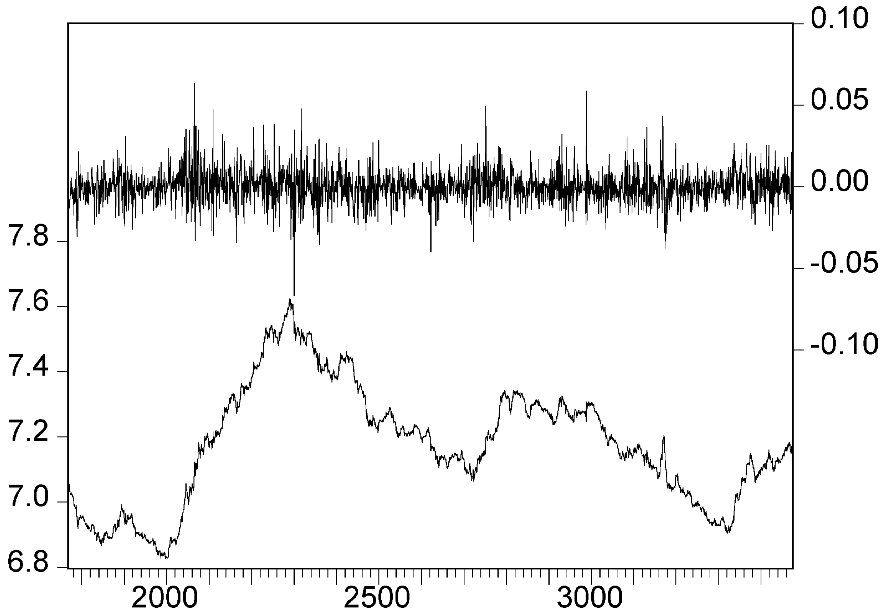

Figure 4: Logarithm of aluminium alloy spot price (bottom) and first difference (top)

As would be expected, price behaviour in the aluminium alloy spot market is similar to that in the futures market. Trends in each market are almost identical. Structural break points observed in the futures price series occur at the same time in the spot price. In general, magnitude of price changes in the spot market appear greater than in the futures market, and extreme observations are slightly greater in absolute value.

Although the copper price (see Figure 5) appears substantially different to the aluminium price in terms of its volatility and first difference, the price levels series contains similar periods of increasing and decreasing trend. However, the variation of the price around the trend is greater for the copper market. Clusters of volatility in copper apparent in the first differences appear more persistent than for aluminium. Furthermore, the copper price is more volatile in the latter half of the sample, particularly around May and June of 1996 (circa observation 2600), where shocks were induced by the collapse of Sumitomo Corporation's manipulation activities in the copper market. During this period, a sudden substantial decrease in the copper price is observed. While this sudden price fall could be interpreted as a structural break, in the context of neighbouring observations, it appears to be part of downward trend in prices over the sub-sample D. Overall, the series is dominated by two long periods of downward trend in prices, with two shorter periods of price increase. Structural break points are identified at 17 January 1989 (observation 770), 27 October 1983 (observation 1976), and 25 January 1995 (observation 2290), resulting in four sub-samples.

Plots in Figure 6 show the log copper spot price and its first difference. The spot market follows similar price trends, and has similar characteristics in price changes, or volatility. Overall, the spot price appears more variable than the futures price. A number of extreme values in each first differences series differ in magnitude. Several price change observations are more extreme in the spot market than in futures. For example, an extremely large positive correction during the May 1996 Sumitomo collapse that occurs in the spot first difference series is reflected to a lesser extent in futures first differences.

Three-month prices for the LME lead futures contract, and its first difference, are shown in Figure 7. Like aluminium and copper, the lead price is also divided into four distinct sub-samples, apparent from examining the data. Break points are identified as occurring on 1 September 1990 (observation 1142), 10 May 1993 (observation 1960) and 17 May 1996 (observation 2621). The timing of two of the three structural break points, those occurring in 1990 and 1996, are distinctly different to the first and third points of structural change that appear in the copper and aluminium markets. First differences show the lead market has a lower degree of clustering of volatility than either aluminium or copper. However there are extreme first difference observations.

The lead spot price has similar characteristics to the lead three-month price. Figure 8 shows the level and first difference of the log spot price. The spot price shows more variation about similar trends to those apparent in the futures price, range of the spot price level is greater than the futures price level. Structural break points occur coincidentally in each series. In general, greater absolute extreme values occur in the spot market first differences than in those for the futures market. The spot market appears more volatile.

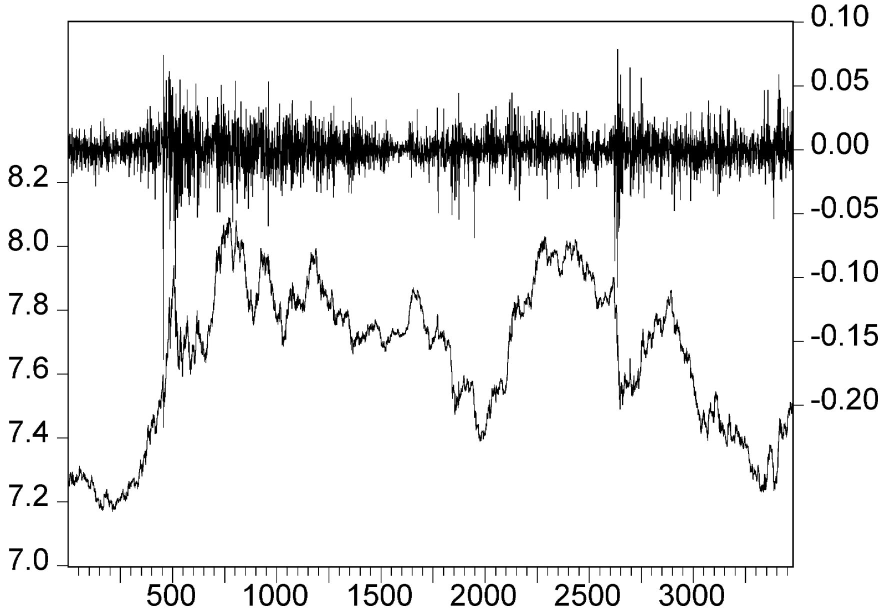

Figure 5: Logarithm of copper 3-month futures price (bottom) and first difference (top)

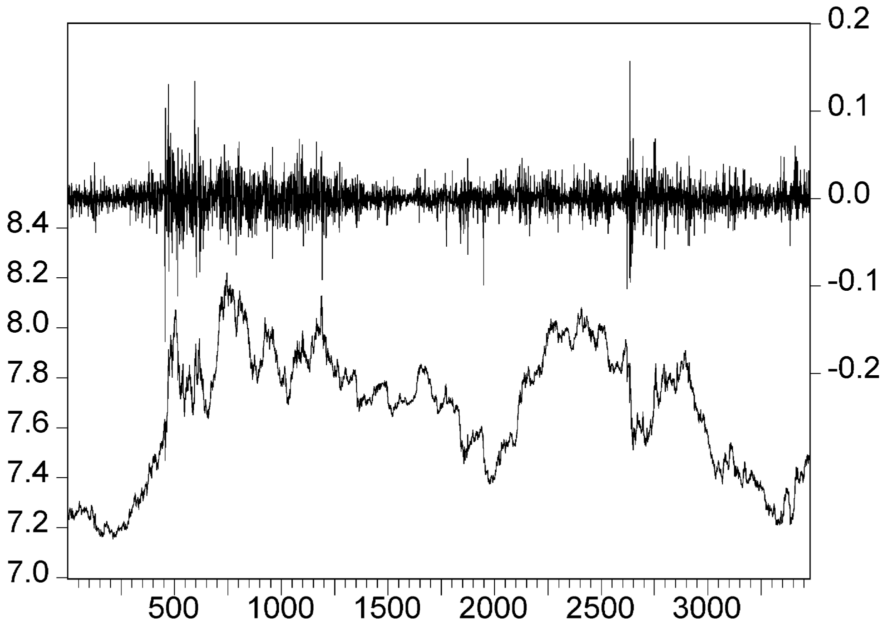

Figure 6: Logarithm of copper spot price (bottom) and first difference (top)

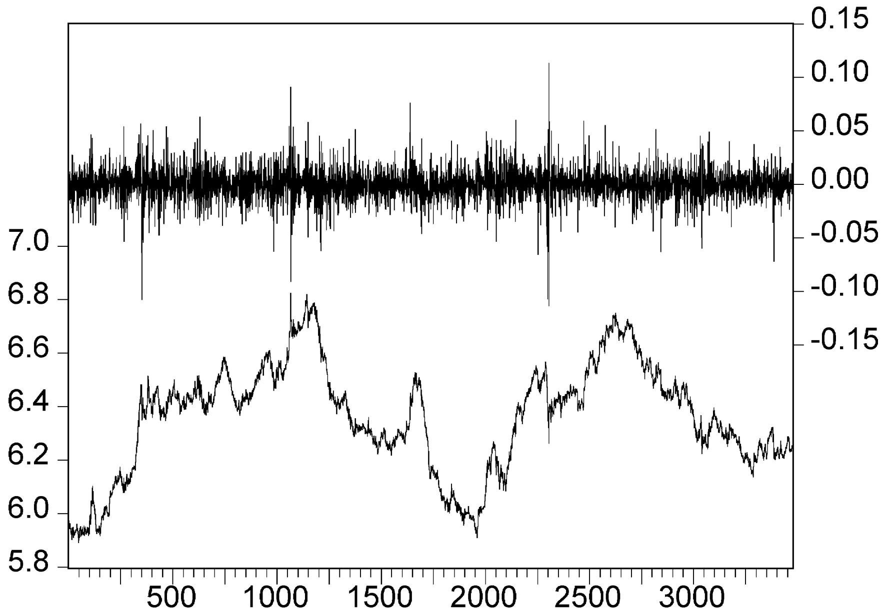

Figure 7: Logarithm of lead 3-month futures price (bottom) and first difference (top)

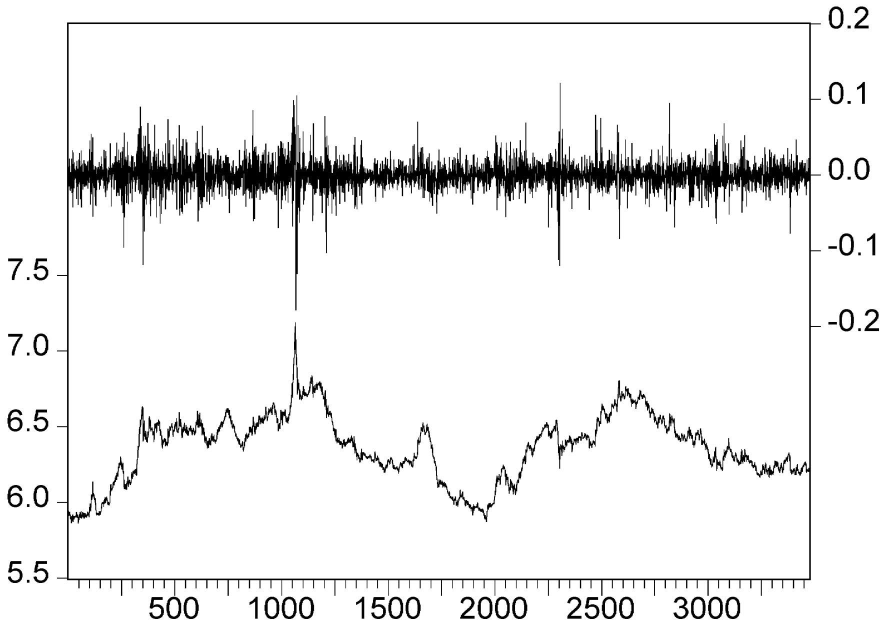

Figure 8: Logarithm of lead spot price (bottom) and first difference (top)

Structural breaks in the nickel price series (see Figure 9) can be identified at 28 March 1988 (observation 567), 29 September 1993 (observation 1956) and 25 January 1995 (observation 2290). Again, the price series is dominated by two long periods of downward trend in prices, each preceded by a short period of price increase. There are frequent extreme observations in the first difference of prices. However, there appears to be a low degree of volatility clustering. The largest extreme observations in the first differences occur around 25 January 1995 (observation 2290), which include two negative shocks and one positive correction. Similar extremes occurring at the same time can be seen in the lead and zinc futures and spot market plots, but not in other metals markets, indicating indicates that a shock common only to lead, nickel and zinc markets occurred.

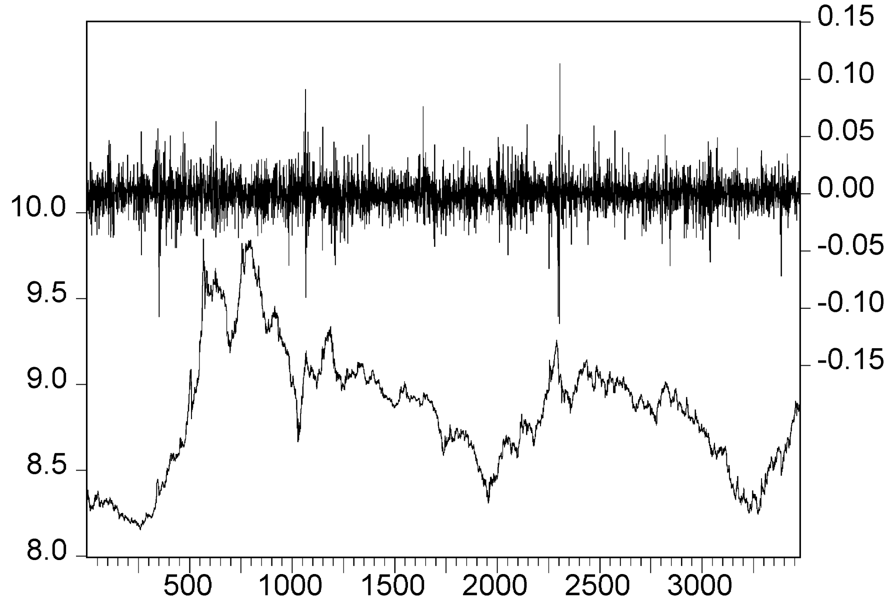

Figure 9: Logarithm of nickel 3-month futures price (bottom) and first difference (top)

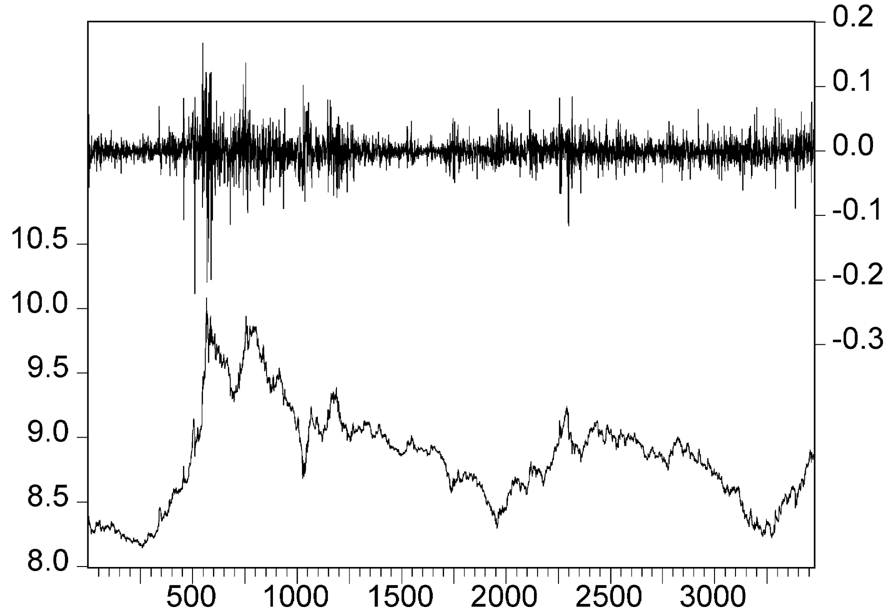

Figure 10: Logarithm of nickel spot price (bottom) and first difference (top)

The log spot price for nickel and its first difference are shown in Figure 10. Spot prices appear to follow a similar trend pattern as nickel futures. At the beginning of the sample, prices are increasing, then there is a longer period of downward trend, followed by a short upwards movement in prices, and then a generally decreasing trend again. However, the first differences of the log spot price are markedly different from the daily change in log futures prices. The first structural break point is identified as 28 March 1988 (observation 567). In the futures first differences, the break point is not associated with a particularly volatile period, and no extreme observations occur in its neighbourhood. However, the situation for the spot price first differences is completely different. The break point is associated with the most volatile period in the nickel market sample. A cluster of volatility in the first differences surrounds the break point, and there are numerous negative and positive extreme observations. Moreover, a daily change in log spot prices of more than 0.1 is commonplace in the months surrounding the break point. There are several further instances of shocks evident in either the spot or futures market that are not obvious in the other. For example, a large negative daily price change occurs in the futures market around observation 700, but is not reflected in the spot market. A large positive correction, greater than 0.1 in terms of a daily price change, occurs in the futures market adjacent to the structural break at 25 January 1995 (observation 2290) is absent in the spot market. The timing and nature of extreme daily price changes in the nickel spot and futures markets appear to differ at several points throughout the sample to a far greater extent than is seen in the other metals markets on the Exchange.

Trading in the tin market was suspended in 1985 after the collapse of the International Tin Council, the body underwriting tin contracts. In 1989, trading resumed. In modelling the tin market, the first 200 observations are removed from the data after the market recommenced operation, and the 2474 observation sample begins at the observation numbered 1000, on 12 December 1989. Figure 11 shows a plot of the tin log futures price and the daily futures price change. Structural break points are observed on the trading days of 20 September 1993 and 18 August 1995, providing three sub-samples for modelling. Each sub-sample appears to be trending. The first sub-sample trends down, the second shows an increasing trend in prices, and in the third sub-sample, prices are decreasing again.

Log spot prices follow an almost identical trend pattern with that observed in the futures market (see Figure 12 for a plot of the tin market spot data). Both the spot and futures market daily price difference series contain few extreme observations. Almost all observations indicate less than a 0.05 daily change in prices. In both markets, a relatively volatile period leads up to the break point at 25 January 1995 (observation 2443). The structural change coincides with the largest negative first difference that occurs both in the spot and futures markets. Daily price changes in both markets are remarkably similar.

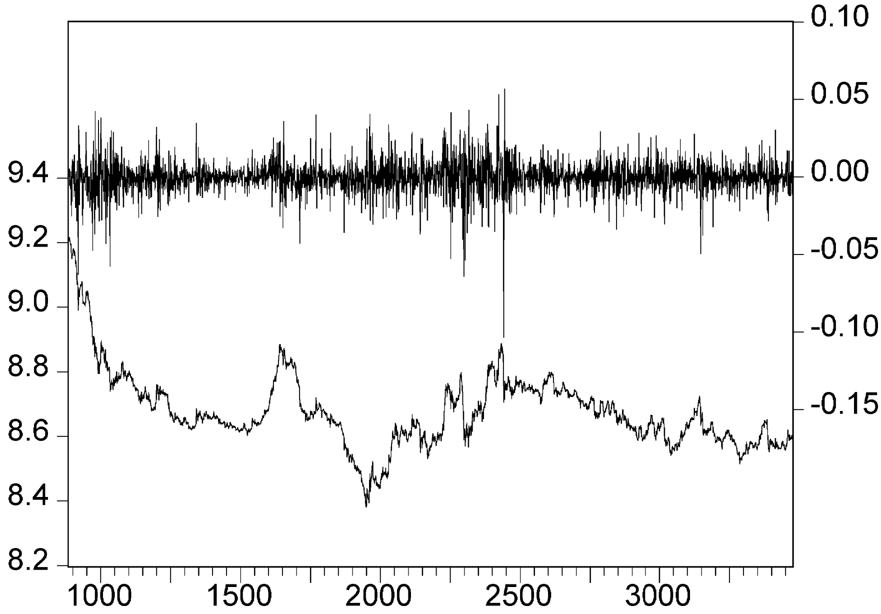

Figure 11: Logarithm of tin 3-month futures price (bottom) and first difference (top)

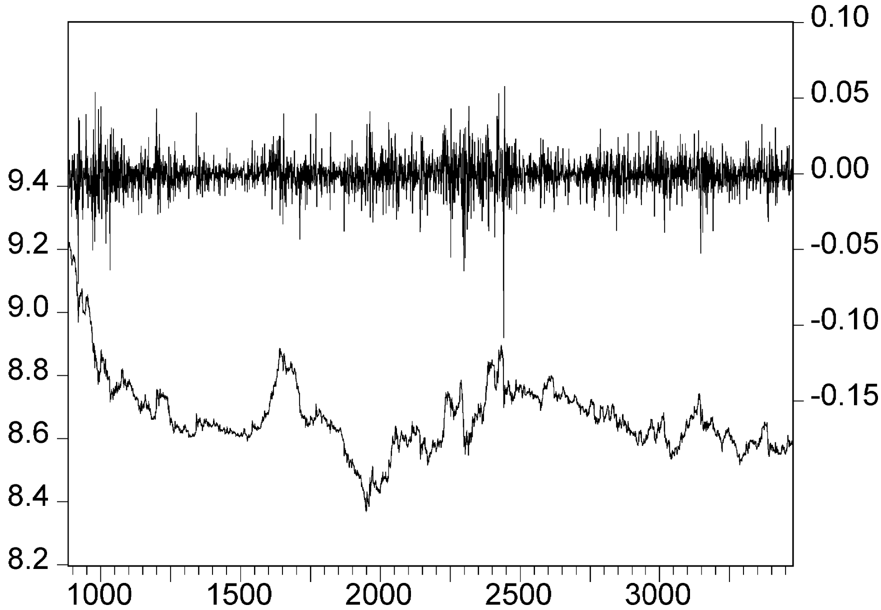

Figure 12: Logarithm of tin spot price (bottom) and first difference (top)

Zinc market futures prices and the first differences of daily futures prices are shown in Figure 13. A plot of the spot price series and its associated daily price changes appear in Figure 14. Structural break points in the futures price level are determined by visual inspection of the data. Two such structural change points occur, the first on 13 March 1989 and the second on 29 September 1993. Each of these points indicates apparent structural change in the futures market, and in each case, the structural change is reflected in the spot market. Three sub-samples are used for modelling long run price relationships. The first sub sample contains an upward trend in zinc futures prices, while the second sub-sample shows decreasing prices. In the third sub-sample, what is unusual for the metals price data considered in this paper is that the sample is not noticeably trending (or a slight upwards trend if anything) over a substantial period amounting to around six years.

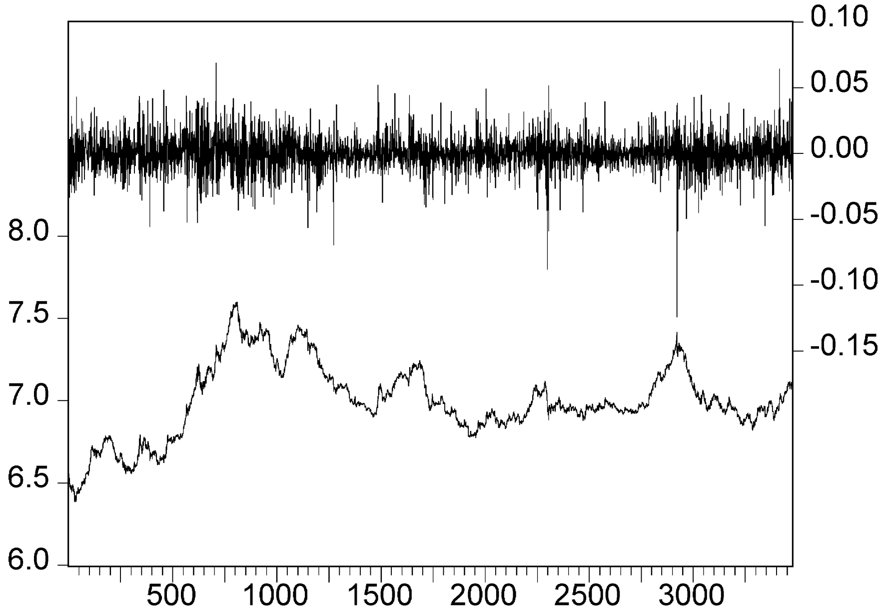

Figure 13: Logarithm of zinc 3-month futures price (bottom) and first difference (top)

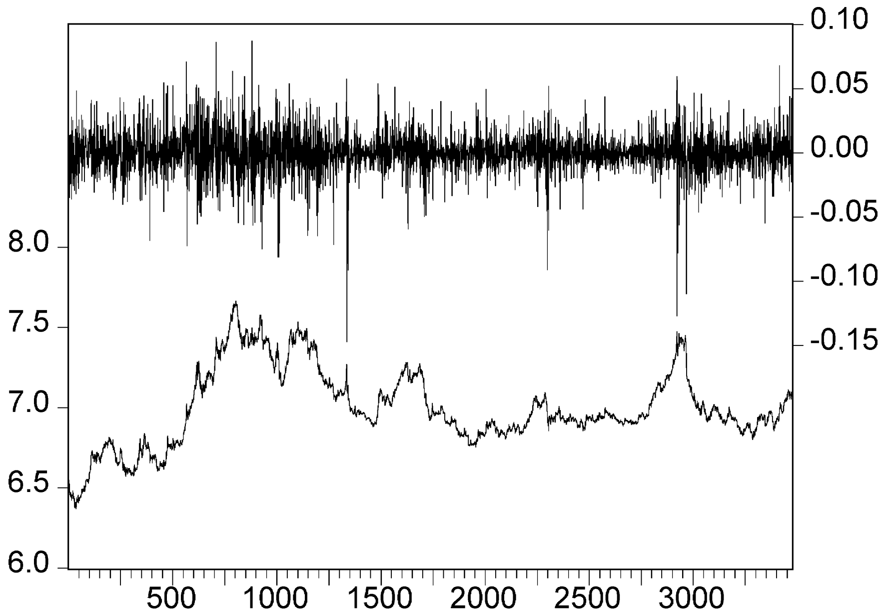

Figure 14: Logarithm of zinc 3-month futures price (bottom) and first difference (top)

While the trends apparent in each sub-sample correspond closely between the futures and spot prices, there are noticeable differences in the price series, particularly in periods of increased volatility. Differences between the series in levels are most noticeable in local price peaks, such as in the region of observations 1650 and 2950. The daily price change series indicate that the spot market for zinc is substantially more volatile than the futures market. Relatively greater clustering of volatility, in terms of larger daily price changes, is evident in the spot market over the futures market. Furthermore, there are a greater number of shocks to daily price changes, and these shocks are also greater in magnitude, in the daily spot price change series, particularly for negative observations. Frequently, shocks enter the spot market and not the futures market. Daily price changes in excess of 0.5 appear far more frequently in the spot market than in the futures market.

The LME holds significant stocks of non-ferrous metals in official LME warehouses in Europe, the United States, Japan and Singapore. Data on official stock levels are also obtained from the LME. Stock levels are recorded on a weekly basis from 1 February 1986 to 26 April 1990, a twice-weekly basis from 30 April 1990 to 30 March 1997, and daily for the remainder of the sample, namely 1 April 1997 to 30 September 1998. A daily series of stock levels is constructed by assuming daily observations are identical to the weekly stock level quote for the relevant week. Where stock level quotes are twice-weekly, the Tuesday quotation is assumed to apply to Monday and Tuesday, while the Friday observation applies to Wednesday, Thursday and Friday. This aggregation may exacerbate the higher volatility observed in daily stock level changes observed for many metals during the first third of the sample. However, given the magnitude of the daily changes in stocks for those metals effected by a high stock level volatility, the reporting of raw data on a twice weekly basis is by no means entirely responsible for the observed volatility in stocks. Plots of the levels over the initial part of the sample indicate high variability in the data.

The stock level, in logarithms, is shown for each metal in the lower panel of Figures 15 to 21. Each Figure also provides the first difference of the log stock level variable in the upper panel. Non-ferrous metals stocks maintained the LME do not necessarily provide a proxy for so called “hidden stocks”, the stocks that producers and consumers of metals hold and manipulate in order to speculate on metals prices. Thus, a firm expecting a future increase in a metal price will accumulate large stocks than required for production. Conversely, under expectations of a future decrease in a metal’s value, a firm will run down its speculative stocks.

Figure 15 shows the aluminium stock level and the daily change in stocks for the entire sample. Stocks of aluminium are particularly volatile during the first third of the sample. This coincides with a volatile period in spot and futures prices for aluminium. The second most visible period of volatility in aluminium prices centred around the break point at observation 2290 coincides with a period of small but consistently negative daily stock level changes, and a sharply declining stock level.

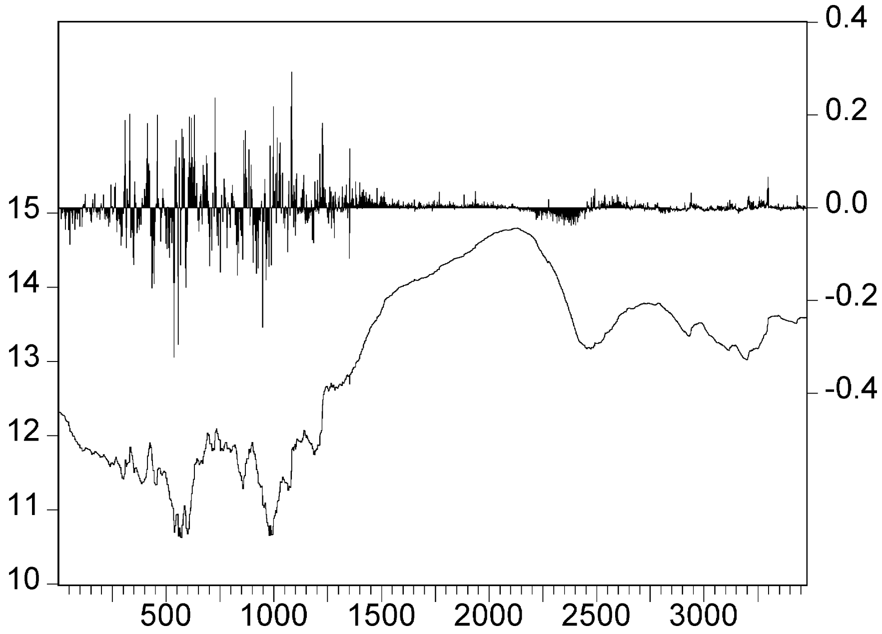

Figure 15: Logarithm of aluminium stock level (bottom) and first difference(top)

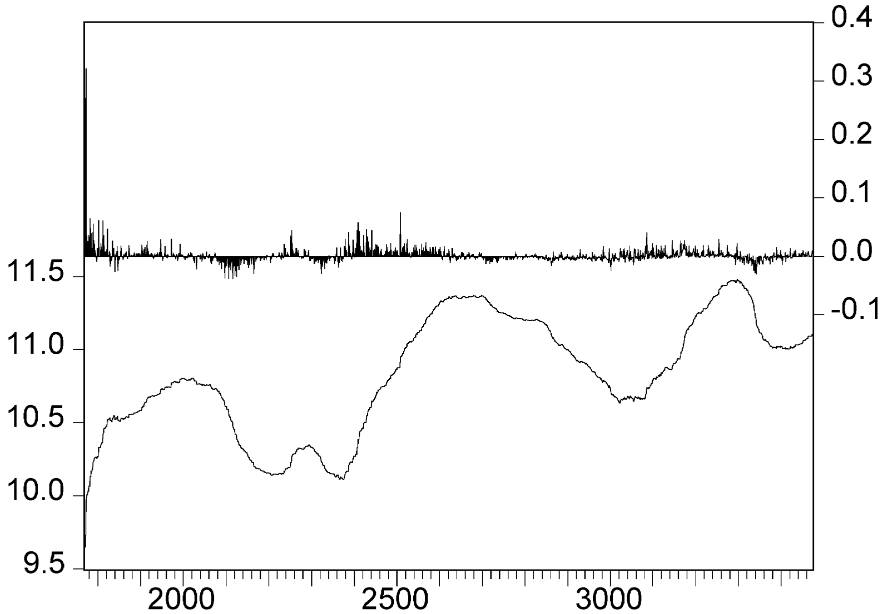

Figure 16: Logarithm of aluminium alloy stock level (bottom)and first difference (top)

Aluminium alloy stocks (see Figure 16) clearly trend upward and show little volatility over the entire sample. The structural break point evident in the price series coincides with a short period of increased stock levels. Daily changes in the stock level are typically small.

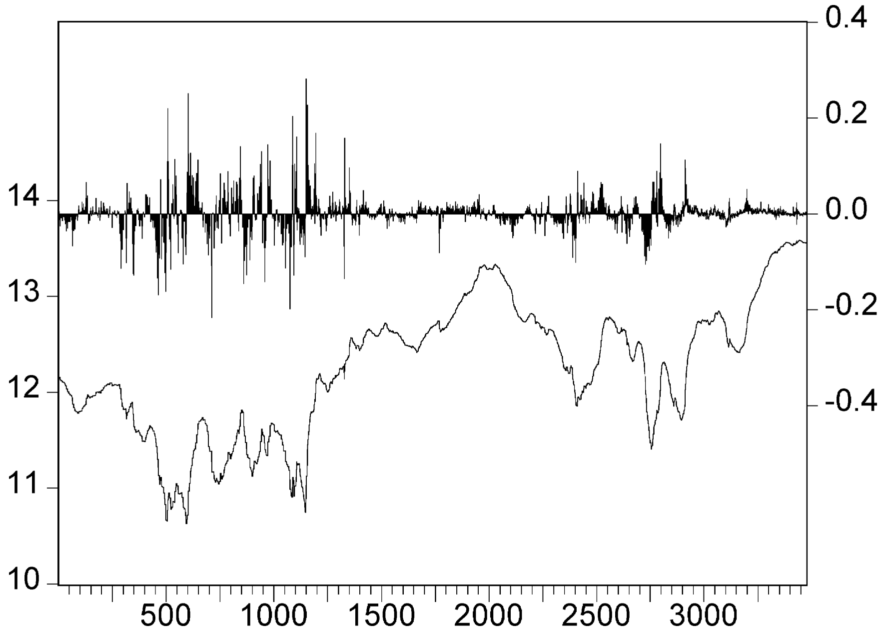

Figure 17: Logarithm of copper stock level (bottom) and first difference (top)

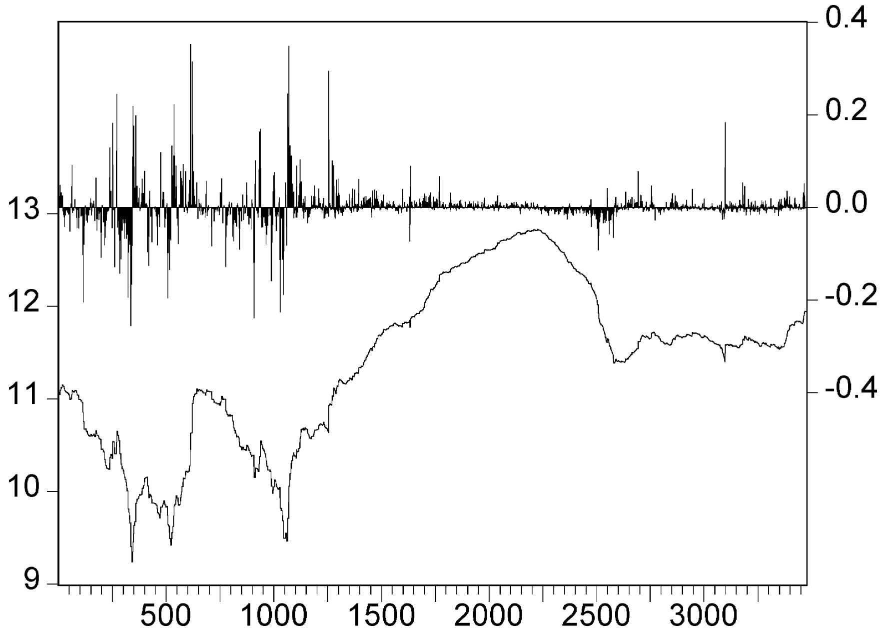

Figure 18: Logarithm of lead stock level (bottom) and first difference (top)

Copper stocks and the daily change in stock levels are shown in Figure 17. Like aluminium, copper stocks are considerably volatile during the first third of the sample. In the copper market, this corresponds to a period of substantial price volatility. While the first break point in the price series does not appear to coincide with any notable features in the stock level variable, the second break point occurs at a peak in copper stocks. Over the year following the collapse of Sumitomo Corporation’s manipulation activities in the copper market, the stock level fluctuates markedly. Over the entire sample, the stock level displays an upward trend.

Figure 18 plots the log lead stock level and the daily change in stocks. The first sub-sample for lead (observations 1 to 1141) is associated with a period of high volatility in stock levels. After the first break point in the lead futures price series, the stock level increases on a steady upwards trend. Shortly after the second break point in the price series, the lead stock level declines, trending downwards. After the final break point in the sample (observation 2621), the lead stock level does not trend up or down, and there is little volatility in daily stock level changes.

Nickel stocks are particularly variable within the first two sub-samples (see Figure 19). After the second break point in the price series (observation 1956), volatility in the stock level first differences is relatively minor. The stock level peaks within sub-sample C (observations 1956 to 2289), and after declining for about one year of trading days, becomes flat and does not trend.

Tin stocks display high volatility at the beginning of the series shown in Figure 20. However, the sample used starts from 12 December 1989 (observation 1000), as the tin market had recently reopened after the contract had been in suspension for several years. For the purposes of the modelling exercise, over the sample considered the tin stock level is relatively less volatile than other metals. Unlike the other metals, however, the tin daily stock level change is more volatile at the end of the sample (over the last 1000 observations) than at the beginning of the sample. The stock level trends upward in sub-sample A, does not trend in sub-sample B, and trends downward in sub-sample C.

Figure 21 displays the log zinc stock level and the first difference of the log stock level. Like aluminium, copper, lead and nickel, daily changes in the zinc stock level are volatile over the first third of the sample, influencing sub-sample A and sub-sample B. There is relatively little volatility in the first difference series over the second half of the entire sample. Within sub-sample A, zinc stocks show no trend, however trend upward in sub-sample B and downward in sub-sample C.

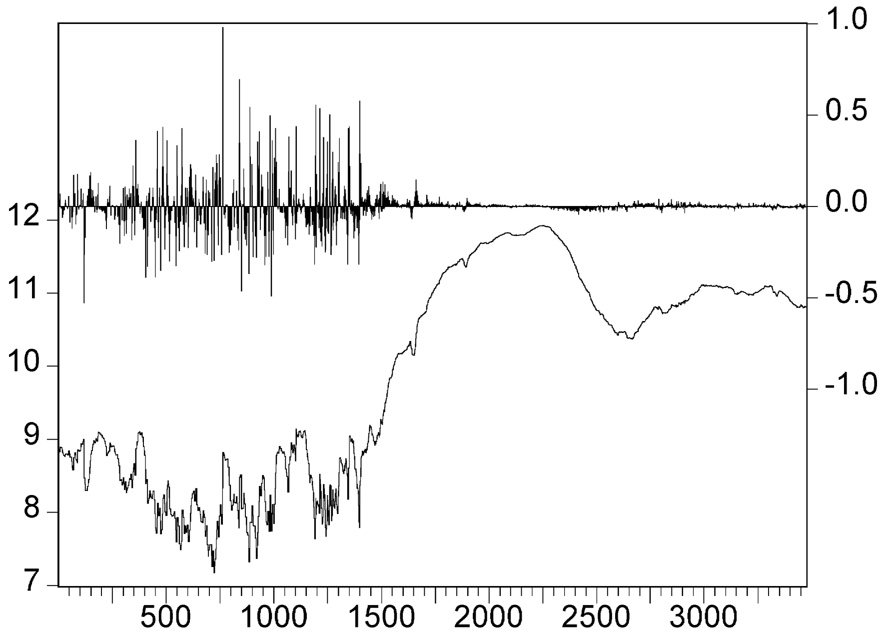

Figure 19: Logarithm of nickel stock level (bottom) and first difference (top)

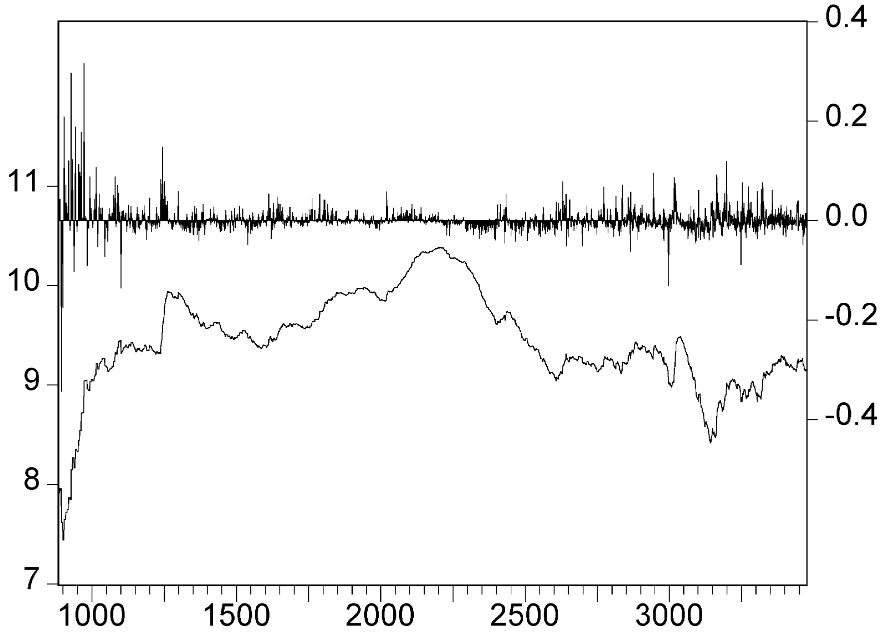

Figure 20: Logarithm of tin stock level (bottom) and first difference (top)

An appropriate proxy for the risk-free interest rate must be determined. Contracts on the LME are denominated in US Dollars, so that a US Dollar interest rate is required. A London based rate is preferred, namely the 3-month US Dollar London Inter-Bank Offer Rate (LIBOR). The LIBOR is an appropriate proxy because of its similarity to the "notional" risk free rate faced by market participants in the LME metals markets. This rate is also the basis upon which interest rates for international trade finance are determined. A sample of daily observations from 1 February 1986 to 30 September 1999 is obtained from DataStream to correspond with the LME data.

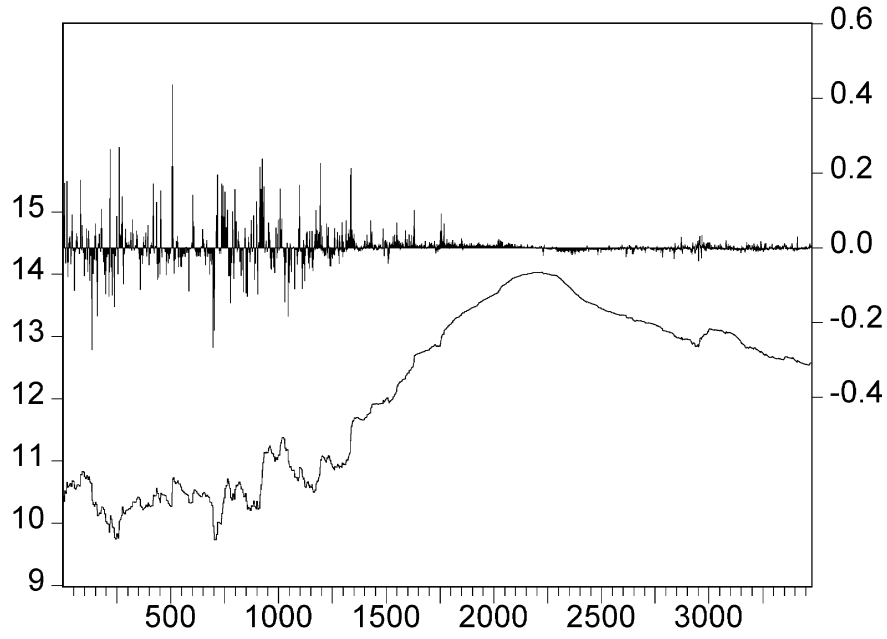

Figure 21: Logarithm of zinc stock level (bottom) and first difference (top)

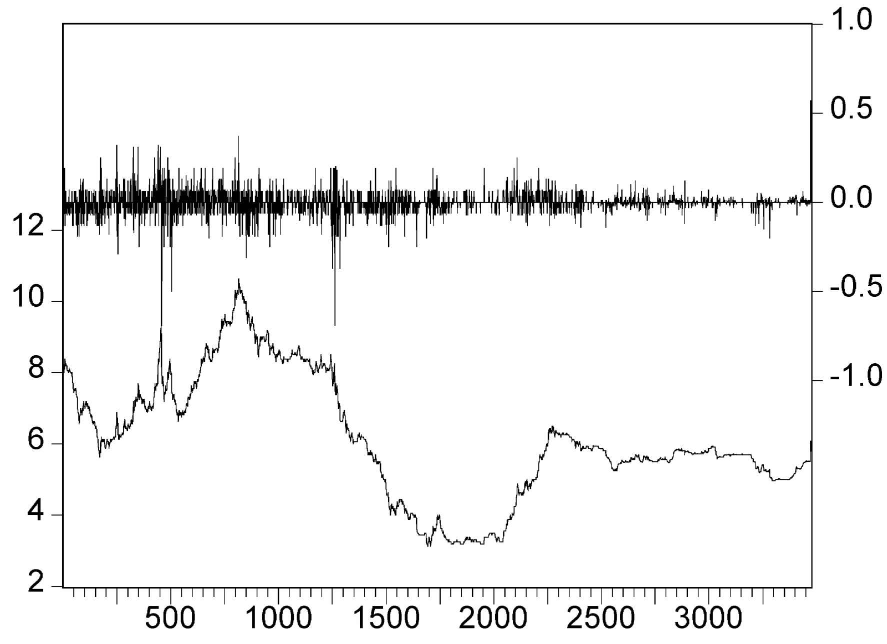

Figure 22: 3-Month USD LIBOR (bottom) and first difference (top)

A plot of the US Dollar 3-month LIBOR is provided in the lower panel of Figure 22, and the upper panel shows its the first difference. The interest rate has varied considerably from a high of over 10% to below 4%. In first differences, the plot shows that daily changes in the interest rate displayed more volatility toward the beginning of the sample, and that volatility has steadily declined since then. A number of extreme negative changes in the rate have occurred. The rate also displays periods of upward and downward trend.

6 Non-stationarity and Unit Roots

Structural breaks are evident in plots of the spot and futures price series over the full sample for each metal. It has been established that the presence of structural breaks affects tests of non-stationarity. Augmented Dickey-Fuller and Phillips-Perron tests are generally biased toward the non-rejection of a unit root (see Perron [1989]).

Examination of the data reveals structural breaks. Data for aluminium, copper, lead and nickel appear to contain three structural breaks, giving four sub-samples. Tin and zinc series contain two structural breaks, giving three sub-samples. Aluminium alloy has one structural break, giving two sub-samples. Sizes of each sub-sample and corresponding dates are provided in Table 1.

The following stationarity testing and cointegration analysis for each metal is based on both the full sample and each sub-sample. In total, five sample sets will be considered for aluminium, copper, lead, and nickel, four sample sets will be considered for tin and zinc, and three sample sets will be used for aluminium alloy. For the full sample, there are assumed to be no structural breaks, and testing of the single full sample is conducted accordingly without explicitly modelling structural breaks. Testing of the sub-samples explicitly accommodates the exogenously specified structural breaks.

The augmented Dickey-Fuller (ADF) test is used to test for the presence of unit roots in each of the spot price, futures price, stock level and interest rate variables in the full sample and the sub-sample sets. Based on the auxiliary regression shown in equation (8), the ADF(p) statistic for a unit root in x_t is given by the t-ratio of the ordinary least squares estimate of β:

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

where Δx_t is the first difference of x_t, t is a deterministic trend term, and ν_t is a stationary error term. Simulated critical values provided by MacKinnon [1991] are used to determine the significance of the ADF test statistics, as the distributional properties of the error term in equation (8) are non-standard.

Plots of the price data (Figures 1 to 14) show the possibility of a deterministic trend in several of the series. Where a trend is present in the data, the test statistics and critical values for the ADF test are substantially different when the auxiliary regression is estimated with and without the trend term. Both the ADF tests with and without trend are considered for determining the order of integration the logarithms of each data series. Where inclusion of the trend term makes a substantial difference to the test statistic, the ADF with trend is used. Plots of the first differences for each variable show that there are no deterministic trends in the first differences of the data. Inclusion of the trend term in the ADF regression makes little difference to the test statistic in the majority of cases, so that the ADF test without trend is used for the first differences of most series.

As the data are daily, unit root testing is conducted with lag lengths of 0 (DF test) to 8 (ADF(8) test). The Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC) and the Hannan-Quinn Criterion (HQC) are used to select the optimal lag length. In general, the AIC suggests a longer lag length than SBC recommends, while HQC frequently falls between the two. However, often the SBC and HQC agree on ADF lag length, and occasionally all three criteria coincide. Where SBC and HQC coincide for a particular lag length, that lag length is used. Where HQC falls between SBC and AIC, the lag length suggested by HQC is used.

The unit root testing procedure is conducted for each sample on the logarithms of the four series for each metal, and on logarithmic first differences, with the results provided in Tables 2 to 8. Unit root tests suggest that each series is integrated of order 1, or I(1), within the full sample, and for each of 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, and the spot and futures prices for the tin sub-sample C. These variables appear to be I(0).

Table 2 provides the results of the unit root tests on the full sample and sub-samples A and B as defined for aluminium alloy. Time trends were used in each ADF test for series in levels, and no time trend was used for series in first differences. The futures price, spot price, stock level and interest rate were all found to be integrated of order 1 in the full sample and each sub-sample.

ADF tests for the aluminium data are presented in Table 3. In the full sample, and sub-samples A, C and D, each variable is I(1). Both the aluminium futures price and spot price appear to be I(0) in sub-sample B. Time trends were used in all tests on levels of variables, and no time trend was used in first differences except for stocks in sub-sample C, where inclusion of a time trend made a substantial difference to the test statistic.

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	-2.563	-6.294	-0.890	-34.474
	Critical Value	-3.416	-2.864	-3.416	-2.864	-3.416	-2.864	-3.416	-2.864

Tests of non-stationarity for the copper data show that the futures price, spot price, stock level and interest rate are integrated of order 1 in the full sample and in each of the four sub-samples (see Table 4). Time trends are employed for the variables in levels in all instances except for spot and futures prices within the full sample, where a trend does not appear necessary. The lag lengths used vary from 0 (DF test) to 8 (ADF(8) test).

The results from ADF tests conducted on lead market data are shown in Table 5. Each of the four variables proves to be I(1) in the full sample, and sub-samples A, B, C, and D. In sub-sample C, a time trend is used for the ADF(5) test on lead stock first differences, as is also the case for the ADF(6) test on the stock level variable. Otherwise, time trends are not used for first differences, but are always used for the variables in levels. In numerous cases, DF tests are optimal, and in other cases lag are employed up to 6.

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	-2.026	-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 6 presents the unit root rests for each variable associated with modelling the long run pricing relationship in the nickel market. A time trend is necessary in each test for variables expressed in levels, but it typically not required for tests on first differenced data. The exceptions are the daily price change of nickel stocks in sub-samples C and D. DF tests show that the interest rate in sub-sample B is I(0). However in sub-samples A, C, and D, and in the full sample, the interest rate is I(1). Futures prices, spot prices, and stocks are I(1) for all samples.

Tests of non-stationarity conducted for tin market variables are summarised in Table 7. Time trends are used in all DF and ADF tests for variables in levels, and are used only in one instance for variables in first differences, that being for daily changes in stocks within sub-sample B. The futures price and spot price for tin are I(0) in sub-sample C, but otherwise are I(1) in the full sample, and sub-samples A and B. Stocks and interest rates are I(1) in the full sample and each of the three sub-samples.

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

In the zinc market, the futures price, spot price, stock level and interest rate are all integrated of order one for each of the three sub-samples and for the full sample (see Table 8). Unit root tests employ a time trend in all tests of variables in levels, except for the spot price within the full sample and the futures price in sub-sample C. The DF test is used on 11 occasions, and otherwise, ADF tests with lag lengths between 1 and eight are conducted.

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	-2.098	-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	-2.228	-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

7 Cointegration Tests and Estimation Results

Tests for the number of cointegrating relationships among the four variables in equation (7), the futures price, spot price, stock level and interest rate, were conducted for each metal using the Johansen maximum likelihood procedure with an unrestricted intercept and an unrestricted trend term. Cointegration tests were conducted in the full sample and sub-samples for all metals, with the exception of sub-sample B for aluminium and sub-sample C for tin, where both the spot and futures prices are I(0).

VAR lag lengths from 1 to 6 were investigated. For the majority of the cointegration tests, the choice of VAR lag length had no discernible effect on the number of cointegrating vectors using the trace and maximal eigenvalue statistics. The parameter estimates of the cointegrating vectors were also typically stable over the choice of VAR lag length. As daily data are used, a VAR lag length of 5 is preferred to ensure the time series properties of the data are reflected in the modelling procedure. For each sample set, the VAR length chosen and the inference based on the corresponding cointegration tests are shown in Table 9. All cointegrating vectors provided in Table 10 are normalised on the futures price coefficient in each case.

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

Prior beliefs as to the nature of the coefficient estimates are formed on the basis of the models presented in section 4. The coefficient of the spot price is expected to be positive and close to one. Equation (6) of the cost-of-carry model requires the stock level coefficient to be positive. The interest rate coefficient is positive under the theory of storage, and a negative sign on the interest rate coefficient is inconsistent with the cost-of-carry model presented. However, the cost-of-carry model of equation (4) may alternatively be viewed as a special case of the risk premium hypothesis or include a risk premium, in which the interest rate is a proxy for the risk premium (see Chow et al. [2000]). This interpretation implies that the interest rate would have a negative effect. Both the interest rate and stock coefficients are expected to be small relative to the spot price parameter.

Under the cost-of-carry model, the absolute magnitude of each of these parameters is expected to be in the vicinity of 0.05, which is small relative to the spot price coefficient. If the interest rate represents a risk premium, its absolute magnitude is expected to be similar to that expected under the cost-of-carry model.

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 zero coefficients on all the variables in the model. The degree of freedom of the LR tests is 3 in each case.

A joint test of zero coefficients on all the endogenous variables in the model suggested by the cointegrating vector is conducted for each sample period (see Table 10). Likelihood ratio tests are conducted in the presence of restrictions on the general model. Restrictions according to the model of equation (2) delete LME stocks and interest rates from the model, while those from equation (4) delete only LME stocks from the model. The general model with interest rates excluded is also considered, and the results of the three tests are provided in Tables 11 to 17. Finally, the validity of restricting stocks and interest rates to have equal, and equal and opposite effects is also tested using likelihood ratio tests (see also Tables 11 to 17).

The existence of one significant cointegrating vector among the variables is consistent with the cost-of-carry model, which implies there should exist only one long run relationship [Heaney, 1998]. This aspect of the cost-of-carry model is violated where two or more cointegrating vectors are shown to be significant according to the trace and maximal eigenvalue cointegration test statistics.

Consider a VAR(1) model:

$$Y_t = \Pi Y_{t-1} + e_t, \qquad (9)$$

where the time series Y_t is a (k x 1) vector of k variables, and e_t is a (k x 1) vector of stationary white noise errors. The matrix Π contains information on the cointegrating relations between the k elements of Y_t. In cointegration analysis, Π can be written as:

$$\Pi = \alpha\beta', \qquad (10)$$

where α and β are (k x r) full rank matrices, with $k \geq r$.

Cointegration operates on the principle of rank reduction of the (k x k) matrix Π in the above equation, such that when $0 < r < k$, there are r cointegrating relations between the k variables. Testing restrictions on the cointegrating vector(s) is only useful when the number of cointegrating vectors r is considerably less than the number of variables k. Where restrictions on the cointegrating vector show that variables can be omitted from the long run relationship such that r = k, regression of the remaining variables can be conducted by using ordinary least squares on levels of the (I(1)) variables.

In the majority of the samples analysed in this paper using cointegration, the trace and maximal eigenvalue statistics indicate 1 cointegrating vector. There are 3 situations where 2 cointegrating vectors are significant. Strict interpretation of the cost-of-carry model would suggest these results reject cost-of-carry for these three situations. However, it is not sensible to test the restriction of joint zero coefficients on the stock and interest rate coefficients in the framework adopted in this paper as k cannot possibly be less than r. Where r = 2, tests of zero coefficients will be conducted on the system of cointegrating relationships for the stock and interest rate coefficients.

The results of this modelling process are discussed for each of the seven LME metals markets in the following sections. Test statistics are evaluated at the 5% level of significance.

7.1 Aluminium

Table 9 provides the number of cointegrating vectors suggested by the test statistics (maximal eigenvalue and trace) and Table 10 shows the significant cointegrating vectors for the full sample and sub-samples A, C, and D of the data for aluminium. As the spot and futures price are I(0) in sub-sample B, it is omitted from the analysis.

In the full sample, the number of cointegrating relationships and the parameter estimates are stable over VAR lengths from 1 to 6. A VAR length of 5 is chosen to ensure the time series properties of the daily data are reflected in the modelling procedure. The coefficient of the spot price is positive and close to 1. Both the interest rate and stock parameters are positive and small, with the stock level having a greater impact than the interest rate. In sub-sample A, the trace statistic indicates one cointegrating vector exists for VAR lengths of 1 to 5, and two exist when the VAR length is six. Similarly, the maximal eigenvalue statistic indicates one cointegrating vector for VAR lengths of 1 to 4, and two for VAR lengths of 5 and 6. A VAR length of 5 is chosen, and the trace statistic is favoured over the maximal eigenvalue. Again the spot price coefficient is positive and close to one, while those of both the stock and interest rate variables are small in magnitude. The stock level coefficient is positive, as expected, while that of the interest rate is negative. A negative coefficient on the interest rate is consistent with a risk premium proxy interpretation of the variable. The trace and maximal eigenvalue statistics indicate there are no long-run relationships among the variables in sub-sample C. Three long-run relationships are present in sub-sample D for VAR lengths 1 and 3 to 6. Where 2 lags are used, 2 cointegrating vectors are significant. A VAR length of 2 is used. The second cointegrating vector is chosen as representing the long-run relationship for the futures price as it conforms with theory: the spot price coefficient is positive and close to one, the stock and interest variables have a small and positive effects. In sub-sample D, the interest rate has a greater effect on the futures price than does the stock level.

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
	B	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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

The LR statistic for the joint test of zero coefficients on the spot, stock and interest variables indicates the null is rejected for each sample tested (see Table 10). No joint test of significance on all three coefficients is conducted in sub-sample D. The second of the two long-run relationships in sub-sample D conforms with the size and magnitude of coefficients expected under the models in section 4. Table 11 provides the results for hypothesis tests for the validity of zero restrictions placed on the model according to the models in equations (2) and (4), and the model with the interest rate excluded. For the full sample, the null is rejected in each case, meaning that the stock level and interest rate should not be deleted from the model, either individually or jointly. As the interest rate and stock level variables should not be excluded from the model, the cost of carry model of equation (7) is supported for the full sample. In addition, the sign of the interest rate coefficient is consistent with the cost-of-carry model. However for sub-sample A, the interest rate, or the stock level variable, or both, can be deleted from the model. The results for sub-sample A support the risk premium hypothesis of equation (2). Each null hypothesis is rejected for sub-sample D, supporting the cost-of-carry model. It should be noted that although the cost-of-carry model is supported by the LR tests, the existence of two long run relationships in sub-sample D violates the theory. Table 11 shows results of tests of equality or opposite effects between the aluminium stock level and the interest rate. The LR tests of these restrictions reject both effects between these variables for the full sample and sub-sample D, but not for sub-sample A.

7.2 Aluminium Alloy

For VAR lengths of 2 to 6, the trace statistic indicates one cointegrating vector, and parameter estimates are stable for the full sample. A VAR length of 5 is used. The spot price coefficient is positive, as is the stock level coefficient, but the interest rate parameter estimate is negative. Both the stock level and interest rate parameter estimates are small, and that for the spot price is greater than one. Results for sub-sample A show that over the choice of VAR length the number of cointegrating vectors is stable at 1, and the parameter estimates to also stable for VAR lengths 1 to 6. The spot price coefficient is positive and less than one, the stock level coefficient is also positive, and the interest rate parameter estimate is close to zero. For sub-sample C, a VAR length of five is used. One long run relationship is significant, and conforms with the prior theory discussed in section 4. The spot price coefficient is close to, but greater than, one and the interest rate coefficient is negative.

For each sample period, the hypothesis of zero coefficients on all variables in the model is rejected (Table 10). LR tests on the general model show that for the full sample and for sub-sample B, neither the stock level nor the interest rate should be omitted from the model (Table 12). Although the interest rate parameter estimate is negative, the LR test supports the cost-of-carry model where the interest rate may be interpreted as a proxy for the risk premium. In sub-sample A, both variables can be deleted individually or jointly, supporting the risk premium hypothesis. The hypothesis of equal effect for the stock and interest rate coefficients is rejected for the full sample and sub-sample B, but not for sub-sample A. Opposite signs for the coefficients is rejected for the full sample, but not for the sub-samples.

7.3 Copper

The number of cointegrating vectors is generally stable over the choice of VAR length for each sample period. However, sub-sample C contains no long-run relationships for VAR lengths from 2 to 6. The full sample and sub-samples A, B, and D each contain one cointegrating relationship among the variables for each VAR length considered. A VAR length of 5 is used to model the long run relationship in each sample except for sub-sample C where one lag is used (Table 9). In each sample, the spot price coefficient is positive and close to one (Table 10). In all cases, except for sub-sample C, the stock level coefficient is positive. The interest rate parameter estimate is negative for the full sample and sub-samples A, B and C, while it is positive in sub-sample D.

In Table 10 the LR test rejects the null hypothesis of zero coefficients on all variables in each sample. Tests of the restrictions imposed by the model in equation (2), shown in Table 13, reject the null in the full sample, sub-sample A and sub-sample D, but not in sub-samples B and C. Identical results apply for the model in equation (4). The restriction on the general model eliminating the interest rate (the "no interest rate model") was not rejected in any of the sub-samples. In LR tests of equal and opposite effects of the stock and interest rate variables, both equal and opposite effects null hypotheses were rejected for the full sample and sub-sample A, but not rejected for sub-samples B and C. Only the opposite effects null was rejected in sub-sample D. The LR test results for the full sample and sub-samples A and D show the stock level variable cannot be excluded from the model, which is consistent with the cost-of-carry model. However, the interest rate may be excluded. In the full sample and sub-sample A, the interest rate coefficient is negative, which is consistent with a risk premium proxy explanation within the cost-of-carry model. In sub-sample D, the interest rate parameter estimate is positive, which is consistent with the standard cost-of-carry explanation. LR tests for sub-samples B and C support the risk premium hypothesis, as both the interest rate and the stock level can be omitted from the model.

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 the 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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

7.4 Lead

Cointegration test statistics (trace and maximal eigenvalue) are stable over VAR lengths of 1 to 6 and indicate one long–run relationship for the full sample, and sub-samples A and C. For sub-sample B, the maximal eigenvalue statistic implies two cointegrating vectors for VAR lengths 1 to 6, while the trace agrees for VAR lengths of 1 and 2 only and thereafter suggests 1 long run relationship. The trace statistic is stable over VAR length in sub-sample D uniformly indicating one cointegration relationship, but the maximal eigenvalue is not. Where the trace and maximal eigenvalue statistics differ, the trace is taken as it achieves higher power. Parameter estimates appear stable over different VAR lengths in the full sample, and sub-samples A, and C. However, the spot price, stock level and interest rate coefficients are not stable in sub-sample B or D. A VAR length of 5 is used for the full sample, and sub-samples A and C to fully incorporate the time series properties of the daily data (see Table 9). For sub-samples B and D, a VAR length of 3 is chosen since this represents the longest lag length under which the cointegrating vector conforms to the expected sign and magnitude of parameters in the models presented. The signs and magnitude of the spot price and stock level coefficients in each sample are as expected under the cost-of-carry model. In the full sample and in sub-samples C and D, the interest rate parameter estimate is positive.

The hypothesis of zero coefficients for all variables in the model is rejected for each sample (see Table 10). Tests of restrictions in the model according to equations (2) and (4), and the no interest rate model, are shown in Table 14. In each sample except sub-sample B, the model in equation (2) is rejected. The model described by equation (4) is rejected for the full sample and sub-sample A, while the no interest rate restriction is rejected for sub-sample D only. In the full sample, and sub-samples A, C, and D, the data support the cost-of-carry model. However, in sub-sample A, the interest rate coefficient is negative, which is not consistent with the standard cost of carry model, but rather with a risk premium proxy interpretation. The risk premium model is supported for sub-sample B only. It should be noted that the interest rate coefficient is also negative for sub-sample B. Restricting the stock level and interest rate variables to be equal is rejected by LR tests for the full sample and sub-sample A, but not for sub-samples B, C and D (see Table 14). The equal magnitude and opposite sign restriction is rejected for the full sample, and sub-samples A and C.

7.5 Nickel

Trace and maximal eigenvalue statistics indicate one cointegrating vector exists for VAR lengths from 1 to 6 in the full sample and sub-sample B, while only the trace is stable indicating once cointegrating vector in sub-sample C. Both the trace and maximal eigenvalue statistics are affected by VAR length in sub-samples A and D (Table 9). Parameter estimates are generally stable over choice of VAR length for all samples. A VAR length of 5 is used for all samples except sub-samples A and D. In sub-sample A, 4 lags are used since no significant long run relationships exist between the variables for 5 lags. Two long-run relationships exist for sub-sample D where 6 lags are used. The coefficient estimates from the cointegrating vectors are consistent with the cost of carry model in that the spot price is positive and close to one, and the stock level and interest rate coefficients are positive, with the exception of the stock level coefficient for sub-sample C and the interest rate coefficient for sub-sample D. A negative estimated coefficient for stocks is inconsistent with the cost-of-carry model, while a negative interest rate coefficient may indicate the rate of interest is a proxy for risk.

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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

LR tests in Table 10 reject a null hypothesis of zero coefficients on all variables in the model for the full sample and sub-samples A, B and C. As two cointegrating vectors are present in sub-sample D, the joint test on three coefficients is not conducted. The restrictions imposed by the model in equation (2) are rejected in the full sample, and sub-samples A and C, but not for sub-samples B or D (see Table 15). However, the model with the stock level variable omitted is not rejected for sub-samples A, B and D, but is rejected for the full sample and sub-sample C. The interest rate can be deleted from the model in the full sample and, sub-samples B and D only. Thus, the risk premium hypothesis is not rejected for sub-samples B or D, but is rejected for all other samples. Different specifications of the cost of carry model are supported for the full sample and sub-samples A and C. Equal effects of the stock level and interest rate variables is rejected for the full sample and sub-sample C, while an equal and opposite effect is also rejected for the same samples.

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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

7.6 Tin

The maximal eigenvalue and trace tests, and cointegrating vector parameters, are generally similar over choice of VAR length in each sample for the tin market. Tests for cointegration indicate one long run relationship exists in each sample for almost all lag lengths. A VAR length of 5 is used in each sample (Table 9). The spot price coefficient is positive and close to one, as expected under both the risk premium and cost-of-carry models. Consistent with the cost-of-carry model, the stock level parameter estimate is positive for the full sample and sub-sample A. However, this is not the case for sub-sample B. The interest rate coefficient is positive in each sample.

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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

The hypothesis of zero coefficients for all variables in the model is rejected (Table 10). For the full sample and sub-sample A, restrictions imposed on the general model which omits the stock level variable, the interest rate, or both, are not rejected. Omitting both the stock level and interest rate, or the interest rate alone, is rejected using LR tests on sub-sample B. However, the stock level variable may be omitted if the interest rate is not. Tests do not reject the equality of interest and stock parameter estimates, as shown in Table 16 for the full sample and sub-sample A. The hypothesis of equal and opposite parameter estimates for these variables is not rejected for any of the three samples. Likelihood ratio tests show that the risk premium hypothesis is not rejected for the full sample and sub-sample A, but is rejected for sub-sample B. In sub-sample B, the cost-of-carry model is supported. Additionally, the restriction according to the specification of the cost of carry model in equation (4) is not rejected. It may be noted that the stock level parameter estimate is of the incorrect sign in sub-sample B, according to the cost-of-carry model.

7.7 Zinc

Cointegration tests are conducted for the full sample and three sub-samples. The number of cointegrating relationships indicated by the tests is stable at one over VAR lengths 1 to 6 in the full sample and sub-sample B. In sub-sample C the trace and maximal eigenvalue statistics agree on the existence of two long run relationships for all lag lengths except 1. The first long-run relationship is selected. A long run relationship is significant for lag lengths up to 4 in sub-sample A. Parameter estimates are similar when compared over different lag lengths for the full sample and sub-sample

A. For both the full sample and sub-sample C, a VAR length of 5 is used. The fourth lag is the highest for which a cointegrating vector exists in sub-sample A. In sub-sample B, a lag length of 3 is used as higher lags produce long-run relationships with a negative stock level coefficient estimate (see Table 9).

For the zinc futures market, the spot price coefficient is positive and close to one, and the stock level coefficient is positive for all samples, consistent with those predicted by the risk premium hypothesis and the cost-of-carry model (Table 10). In sub-sample C, the magnitude of the stock level coefficient is larger than expected. Although the interest rate parameter estimate is positive for the full sample and sub-sample A, it is negative for sub-samples B and C. The interest rate parameter estimate is consistent with the standard cost-of-carry model for the full sample and sub-sample A, and with the risk proxy interpretation for sub-samples B and C.

For the joint test of zero coefficients on each variable in the general model, the null is rejected for each sample, except sub-sample C where no test is conducted. The LR test statistics for the models in equations (2) and (4) are significant for the full sample, and sub-samples A and C, but not sub-sample B (see Table 17). For the full sample and sub-samples A and B, the model without the interest rate is not rejected, but it is rejected for sub-sample C. In the full sample and sub-sample A, coefficients of the stock level and the interest rate are neither equal, nor equal and of opposite sign, according to the LR test statistics in Table 17. However, in sub-sample B, neither of the null hypotheses is rejected according to the LR statistics. For sub-sample C, equality of the estimated coefficients is rejected, but an equal and opposite effect is not. For the full sample and sub-sample A, the cost-of-carry model is supported. It should be noted that LR tests do not reject exclusion of the interest rate variable in either sample. The risk premium hypothesis is not rejected for sub-sample B. Although two cointegrating vectors were significant for sub-sample C, the LR tests suggest the cost of carry model is supported.

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 the zero restriction(s) imposed on the model. The degrees of freedom of the tests are given in parentheses.

8 Conclusion

Based on the risk premium and cost-of-carry models, where the futures price, spot price, interest rate, and stock level variables all contain stochastic trends, a framework for estimating long run pricing models for LME metals futures prices using cointegration was specified. This approach was undertaken to accommodate the common time series properties of financial data, particularly the presence of stochastic trends in price levels. Three-month futures contracts for seven LME metals markets are considered, namely aluminium, aluminium alloy, copper, lead, nickel, tin and zinc.

After testing for non-stationarity, assuming no structural breaks and also explicitly accommodating exogenously specified structural breaks for the data in each metals market, spot, futures, stock level and interest rates were found to be integrated of order 1 in the majority of samples. The exceptions where series were found to be stationary are the spot and futures prices in aluminium sub-sample B and tin sub-sample C, and the interest rate for nickel sub-sample B.

In most of the samples considered for the seven metals markets, tests for cointegration determined the existence of one statistically significant long run relationship among the futures price, spot price, stock level and interest rate. Two long run relationships were found in aluminium sub-sample D, nickel sub-sample D, and for the zinc market in sub-sample C.

Table 18: Inference summary

Market	Full Sample	Sample A	Sample B	Sample C	Sample D
Aluminium Alloy	C-O-C	R P H	C-O-C	-	-
Aluminium	C-O-C	R P H	(I(0) Var)	(No CVs)	C-O-C[3]
Copper	C-O-C[1]	C-O-C[1]	R P H	R P H	C-O-C[1]
Lead	C-O-C[1]	C-O-C[1]	R P H	C-O-C[1,2]	C-O-C[2]
Nickel	C-O-C[1]	C-O-C[2]	R P H	C-O-C	R P H[1]
Tin	R P H	R P H	C-O-C[2]	(I(0) Var)	-
Zinc	C-O-C[1]	C-O-C[1]	R P H	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.

Table 18 summarises the inferences resulting from the LR tests on the model specified in equation (7) for each metal over the full sample and each sub-sample, based on the restrictions implied by equations (2) and (4), and the no-interest rate model. For the full sample, the long run relationship is best described by the cost-of-carry model for aluminium, aluminium alloy, copper, lead, nickel, and zinc. The risk premium hypothesis is rejected. Only in the case of the tin market is the risk premium hypothesis not rejected over the full sample. It should be noted that for copper, lead, nickel, and zinc, the interest rate variable may be excluded. In the sub-samples, the risk premium model is not rejected as frequently, and applies to the long run futures pricing relationship in nine sub-samples. The cost-of-carry model applies to a total of twelve sub-samples. Of these twelve cases, the interest rate may be excluded in four models, three cases are represented by the cost-of-carry model of equation (4) where the stock level may be excluded, and in one model the interest rate and stock level variables may be individually, but not jointly, excluded. In each instance, exclusion of both the stock level and interest rate is rejected. In two instances, while cointegration tests indicate two long-run relationships, LR tests support the cost of carry model in each sub-sample.

For all markets except tin, the cost of carry model holds over the full sample. However, structural change occurs in each market, influencing the appropriate model for the pricing of futures contracts. During some periods, the risk premium model is supported for each metal. This paper provides evidence that either of the risk premium and cost-of-carry models can usefully be applied to each of the LME metals markets over different sub-samples.

Acknowledgements

The authors are grateful to Celso Brunetti and Christopher Gilbert for providing their data, and Dick van Dijk, Richard Heaney, and participants at the International Congress on Modelling and Simulation, Hamilton, New Zealand, 1999, for helpful comments. The first author would like to acknowledge the financial support of the Department of Economics, University of Western Australia, and the Australian Research Council. The second author is most grateful for the financial support of the Australian Research Council and the Center for International Research on the Japanese Economy, Faculty of Economics, University of Tokyo.

References

Beck, S.E., Cointegration and market efficiency in commodities futures markets, *Applied Economics*, 26, 249-257, 1994.

Bracker, K. and K. L. Smith, Detecting and modelling changing volatility in the copper futures market, *Journal of Futures Markets*, 19, 79-100, 1999.

Brenner, R.J. and K.F. Kroner, Arbitrage, cointegration and testing the unbiasedness hypothesis in financial markets, *Journal of Financial and Quantitative Analysis*, 30, 23-42, 1995.

Brunetti, C. and C.L. Gilbert, Metals price volatility, 1972-95, *Resources Policy*, 21, 237-254, 1995.

Brunetti C. and C.L. Gilbert, Are metals' prices becoming more volatile?, *Proceedings of the Mineral Economics and Management Society*, 58-72, 1996.

Canarella, G. and S.K. Pollard, The ‘efficiency’ of the London Metal Exchange: a test with overlapping and non-overlapping data, *Journal of Banking and Finance*, 10, 575-593, 1986.

Chang, E.C., C. Chen and S.N. Chen, Risk and return in copper, platinum, and silver futures, *Journal of Futures Markets*, 10, 29-39, 1990.

Choksi, S., Spot and futures prices in copper: the speculative link, *Journal of Post Keynesian Economics*, 6, 433-448, 1984.

Chow, Y.-F., M. McAleer and J.M. Sequeira, Pricing of forward and futures contracts, *Journal of Economic Surveys*, 14, 215-253, 2000.

Chowdhury, A.R., Futures market efficiency: evidence from cointegration tests, *Journal of Futures Markets*, 11, 577-589, 1991.

Doornik, J.A., D.F. Hendry and B. Nielson, Inference in cointegrating models: UK M1 revisited, in *Practical Issues in Cointegration Analysis*, M. McAleer and L. Oxley (eds.), Blackwell, Oxford, 117-156, 1999.

Engle, R.F. and C.W.J. Granger, Co-integration and error-correction: Representation, estimation and testing, *Econometrica*, 55, 251-276, 1987.

Fama E.F. and K.R. French, Business cycles and the behaviour of metals prices, *Journal of Finance*, 43, 1075-1093, 1988.

Franses, P.H. and P. Kofman, An empirical test for parities between metal prices at the LME, *Journal of Futures Markets*, 11, 729-736, 1991.

Fraser, P. and R. MacDonald, Spot and forward metals prices: efficiency and time series behaviour, *Review of Futures Markets*, 11, 24-34, 1992.

Gilbert, C.L., Manipulation of metals futures: lessons learned from Sumitomo, *Discussion Paper No. 1537*, Centre for Economic Policy Research, 1996.

Goss, B.A., The semi-strong form efficiency of the London Metal Exchange, *Applied Economics*, 15, 681-698, 1983.

Hall, S. G., An application of the stochastic GARCH-in-mean model to risk premia in the London Metal Exchange, *The Manchester School*, 59, 57-71, 1991.

Hall, S.G. and M.P. Taylor, Modelling risk premia in commodity forward prices: some evidence from the London Metal Exchange, *Review of Futures Markets*, 8, 200-217, 1989.

Hardouvelis G.A. and D. Kim, Margin requirements, price fluctuations, and market participation in metal futures, *Journal of Money, Credit, and Banking*, 27, 659-671, 1995.

Heaney, R., A test of the cost-of carry relationship using the London Metal Exchange lead contract, *Journal of Futures Markets*, 18, 177-200, 1998.

Hsieh, D.A. and N. Kulatilaka, Rational expectations and risk premia in forward markets: primary metals at the London Metal Exchange, *Journal of Finance*, 37, 1199-1207, 1982.

Johansen, S., Statistical analysis of cointegrating vectors, *Journal of Economic Dynamics and Control*, 12, 231-254, 1988.

Johansen, S., Estimation and hypothesis testing of cointegrating vectors in Gaussian vector autoregressive models, *Econometrica*, 59, 1551-80, 1991.

Johansen, S., *Likelihood-based Inference in Cointegrated Vector Autoregressive Models*, Oxford University Press, Oxford, 1995.

Krehbiel, T. and L.C. Adkins, Cointegration tests of the unbiased expectations hypothesis in metals markets, *Journal of Futures Markets*, 13, 753-763, 1993.

Larson, D.F., Copper and the negative price of storage, *Working Paper No. 1282*, World Bank, Washington, 1994.

MacKinnon, J.G., Critical values for cointegration tests, in *Long Run Relationships: Readings in Cointegration*, R.F. Engle and C.W.J. Granger (eds.), Oxford University Press, New York, 267-87, 1991.

MacDonald, R. and M.P. Taylor, Testing rational expectations and efficiency in the London Metal Exchange, *Oxford Bulletin of Economics and Statistics*, 50, 41-52, 1988a.

MacDonald, R. and M.P. Taylor, Metal prices, efficiency and cointegration: Some evidence from the London Metal Exchange, *Bulletin of Economic Research*, 40, 235-239, 1988b.

MacDonald, R. and M.P. Taylor, Rational expectations, risk and efficiency in the London Metal Exchange: an empirical analysis, *Applied Economics*, 21, 143-153, 1989.

Moore M. J. and U. Cullen, Speculative efficiency on the London Metal Exchange, *The Manchester School*, 63, 235-256, 1995.

Ng, V.K. and S.C. Pirrong, Fundamentals and volatility: storage, spreads, and the dynamics of metals prices, *Journal of Business*, 67, 203-230, 1994.

Park, J.Y. and P.C.B. Phillips, Statistical inference in regressions with integrated processes: part 2, *Econometric Theory*, 5, 95-132, 1989.

Perron, P., The great crash, the oil price shock, and the unit root hypothesis, *Econometrica*, 57, 1361-1401, 1989.

Pesaran, M.H. and R.P. Smith, Structural analysis of cointegrating VARs, in *Practical Issues in Cointegration Analysis*, M. McAleer and L. Oxley (eds.), Blackwell, Oxford, 7-53, 1999.

Phillips, P.C.B. and Z. Xiao, A primer on unit root testing, in *Practical Issues in Cointegration Analysis*, M. McAleer and L. Oxley (eds.), Blackwell, Oxford, 7-53, 1999.

Sephton, P.S. and D.K. Cochrane, A note on the efficiency of the London Metal Exchange, *Economics Letters*, 33, 341-345, 1990.

Sephton, P.S. and D.K. Cochrane, The efficiency of the London Metal Exchange: another look at the evidence, *Applied Economics*, 23, 669-674, 1991.

Sequeira, J.M. and M. McAleer, Testing the risk premium and cost-of-carry hypotheses for currency futures contracts, *Applied Financial Economics*, 10, 277-289, 2000a.

Sequeira, J. and M. McAleer, A market-augmented model for SIMEX Brent crude oil futures contracts, *Applied Financial Economics*, 10, 543-552, 2000b.

Shyy, G. and B. Butcher, Price equilibrium and transmission in a controlled economy: a case study of the metal exchange in China, *Journal of Futures Markets*, 14, 877-890, 1994.

Teyssiere, G.P., C. Brunetti and C.L. Gilbert, Non-ferrous metals price volatility: a fractionally integrated process?, in R. Smith (ed.), *Managing Metals Price Risk*, Risk Publications, London, 141-152, 1997.

Working, H., The theory of the price of storage, *American Economic Review*, 39, 1254-62, 1949.

Zivot, E., Cointegration and forward and spot exchange rate regressions, *Journal of International Money and Finance*, 19, 785-812, 2000.