

# **FESTSCHRIFT SYMPOSIUM FOR**

**WALTER C. LABYS**

**Agricultural and Resource Economics  
West Virginia University**

**May 7, 2007**

## **METAL PRICES AND THE SUPPLY OF STORAGE**

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### **Abstract**

The purpose of this paper is to empirically evaluate the supply of storage theory in relation to metals traded on the London Metal Exchange. Spot and futures prices are examined in relation to now existing data for aluminium, copper, lead and zinc inventories. Our contribution is to question the empirical rigor of this theory and to show that most of the explanatory power rests between stock, cash and futures prices, not the basis. Regression analysis is applied to the storage relationship. Unit root tests provide evidence for integration. We then test for cointegration among stocks, cash and futures prices employing the Johansen test procedure. Confirmation of cointegration dictates that causality be tested using the corresponding Granger error correction model. Results of this analysis including variance decomposition suggest that inventories drive price movements rather than the reverse causality.

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# **METAL PRICES AND THE SUPPLY OF STORAGE**

## **INTRODUCTION**

Inventory behaviour provides a key to understanding price and equilibrium adjustment processes in international metals markets; yet it has received only minimal attention in the economic and econometric analyses of these markets. One reason for this has been the lack of suitable inventory or stock data. Another has been the lack of any uniform theory of inventory behaviour or inventory-price relationship to serve as a basis for research. Among the diverse theories that have appeared, the supply of storage was one of the first. Attempts have been made to apply this theory to metal markets but with only mixed results. One problem with such studies has been the lack of useful inventory data. The purpose of this paper is to re-examine this theory by employing time series tests based on now existing stock data for aluminium, copper, lead and zinc. Our contribution is to question the rigor of this theory and to show that most of its explanatory power rests between stock, cash and futures prices, not the basis. Employing unit root tests for preliminary integration analysis, we then test for cointegration among stocks, cash and futures prices employing the Johansen test procedure. Confirmation of cointegration dictates that causality be tested using the corresponding Granger error correction model. Results of this analysis including variance decomposition suggest that inventories drive price movements rather than the reverse causality.

This paper consists of the following parts: inventory behaviour and prices, the supply of storage theory, the empirical storage curve, cointegration and causality, and conclusions.

## **INVENTORY BEHAVIOR AND PRICES**

Among received studies that have attempted to analyse the inventory and price relationship, not many exist. The principal effort has been to determine why commodity producers, consumers and dealers hold stocks and in what quantities. Among early efforts, Brennan (1958) employing agricultural commodity data to evaluate the supply of storage theory developed by Working (1949), Kaldor (1939) and Keynes (1930).

Concerning other theories that have been proposed to explain inventory behaviour are the accelerator, asset returns, buffer stocks, quadratic or S, production smoothing, and optimization, e.g. see reviews by ..... Supply of storage implies that firms will adjust their stock levels until the marginal revenue of holding stocks equals their marginal cost, the latter determined by coverage and stockout yields as well as cost of storage. Tests of this theory have followed, for example, in studies by Brennan (1958,1991) on precious metals, lumber, butter, eggs, wheat, oats and wheat; Telser (1958) on cotton and wheat, Weymar (19 ) on cocoa; and Considine and Heo (2000) on crude oil and its products.

Earlier studies dealing with supply of storage that focus particularly on metals inventory behaviour include Burrows (1971) (check??) and Ghosh et al. (1987) (check??). Among more recent applications, Bresnahan and Suslow (1985) have investigated copper market dynamics in the context of the London Metal Exchange (LME) by concentrating on the asset character of stocks. They examine the rate of return of holding copper and the implications of inventory stockouts on this rate of return. Thurman (1988) interprets the supply of storage by estimating a structural model of stock equilibrium that utilizes in addition direct measurements of stocks. Pindyck (1994) concentrates on the cost aspect by studying how consumers and producers balance cost adjusting consumption and production with the costs of decreasing inventory holdings as a reaction to metal price fluctuations. As the spread between spot and futures prices varies, the costs of drawing down inventories determine just what quantity of inventories will be held. His conclusions confirm production cost smoothing behaviour, in which inventories are used to shift production to periods in which costs are low and in which inventories are used to avoid stockouts and to reduce scheduling costs. The attempt of Labys and Lord (1991) was to explain fluctuations in inventories as a response to how markets move in and out of equilibrium. Emphasis is placed more on production and consumption than price adjustments using the Granger and Lee (1988) multicointegration approach to equilibrium relationships.

Fama and French (1988) have employed spot and futures prices to examine whether the convenience yield on inventory falls at a decreasing rate as inventory increases for aluminum, copper, gold, lead, platinum, silver, tin and zinc.. The implication of the theory examined is that futures prices are less variable than spot prices

with inventory is low. But when inventories are high, spot and futures prices should have roughly the same variability. They explain price variability according to whether inventories are low or high and relate inventory levels to positive demand shocks induced by business cycle activity. While Fama and French focus on the variance of the basis, Ng and Pirrong (1994) estimate the effect of the basis on spot and futures return variances and on the correlation between spot and futures returns also for the nonferrous metals. The authors have examined volatility at each point in the sample to test the related Samuelson (1965) hypothesis that spot prices should vary more than futures prices. Heaney (2001) has investigated how estimates of convenience yield can be used to explain differences between imputed and actual futures prices for copper, lead and zinc.

What is lacking in most studies is that actual metals inventory data have not been employed in reaching any conclusions about the metals inventory and price relationship, with the exception of Pindyck (1994) and Thurman (1988). In fact, inferences about the nature of inventory levels and behaviour have been made only in terms of the basis or the inter-temporal price spread and related cost and financial factors. What we know, however, is that the behaviour of a variety of different forms of inventories are important for understanding metal industry price movements. Consumers acting as manufacturers or processors carry operational stocks to smooth activity of their production and distribution systems to serve as a buffer against interruptions such as for maintenance and to facilitate transactions accounting for periodic or cyclical variations. The convenience for manufacturers comes from avoiding plant closings and maintaining reasonable cost coverage against finished product price quotations. While these activities require only low stock holdings, additional stocks will be held only with the expectation of a return or risk premium for doing so.

Producers maintain stocks to facilitate sales and deliveries but sometimes are forced to carry inventories from periods of seasonally high production to periods of low production because of cyclical turndowns in sales. Dealers or merchants carry stocks just to facilitate their everyday business of buying and selling metals, some of which call for forward delivery. Finally the commodity exchanges themselves hold inventories not only to accommodate speculative transactions but also to better deal with market physical surpluses and deficits.

## THE THEORY OF STORAGE

The theory of the supply of storage has expanded in its interpretation, since its appearance as Keynes (1930) theory of normal backwardation. Working (1949) criticized this approach as to simply implying the transfer of risk from speculator to hedger and instead hypothesized that the intertemporal relationship between spot and futures prices was determined by the net cost of carrying stocks. The soon to be found advantage of this theory was that it is relatively easy to test. Because of the difficulties of obtaining meaningful inventory data though, only the agricultural and petroleum studies have been able to employ stock data. Here we take advantage of the metal inventory time series that have been compiled in recent years to evaluate the inventory and price relationship in physical terms.

Brennan (1958) provided the first testable version of the theory by solving the supply of storage function from the equilibrium conditions between the demand for storage and the supply of storage. Here storage refers to commodities as inventories or physical stocks and not to storage space. The demand for storage stems from consumers who want storage such that the flow of commodities for sale will be made relatively stable. The supply of storage refers to the task of carrying stocks of a commodity from one period into the next and implies that that firms will adjust their stock levels until the marginal revenue of holding stocks or marginal convenience yield equals their marginal cost, the latter determined by coverage and stockout yields as well as the cost of storage. In a competitive market firms will hold stocks from one period to the next if the net marginal cost of storage equals the expected price. Equilibrium requires that the net marginal cost of storage (positive or negative) must equal the price of storage. The total net cost of storage was defined by Brennan as a function of three components: physical costs of storage ( $o_t$ ), risk aversion factors ( $r_t$ ) and convenience yield ( $c_t$ ). Physical costs of storage include interest expense, rent, insurance, handling, and other direct costs associated with storing a product. Interest costs, in particular, provide a transparent view of how storage costs are moving and can reflect the influence of changing business cycles. These costs are assumed to increase at constant rates except at high levels of

inventory. At higher inventory levels physical storage costs rise quickly because of capacity limits.

The term net cost results from subtracting the convenience yield from the other two components. The total net cost of storage ( $m_t$ ) can then be defined in terms of ending stocks ( $I_t$ ) as follows.

$$m_t(I_t) = o_t(I_t) + r_t(I_t) - c_t(I_t)$$

The marginal values of these terms can be obtained by differentiating with respect to  $I_t$ .

$$m'_t > 0 \text{ or } < 0 \text{ (marginal net total cost of storage)}$$

$$o'_t > 0 \text{ and } o''_t \geq 0 \text{ (marginal physical costs)}$$

$$r'_t > 0 \text{ and } r''_t \geq 0 \text{ (marginal risk aversion)}$$

$$c'_t \geq 0 \text{ and } c''_t \leq 0 \text{ (marginal convenience yield)}$$

The marginal costs and marginal risk aversion are either constant or are increasing functions of stocks. The higher the level of stocks, the greater will be the loss to the firm from an unexpected price fall. The marginal convenience yield declines and reaches zero at a given level of stocks. At low levels of inventories manufacturers and processors could possibly reach stockouts that could reduce orders fulfilments or limit capacity utilization. Since the costs of obtaining additional inventories may become high, the convenience yield becomes high with low stock levels, since pipeline stocks are necessary.

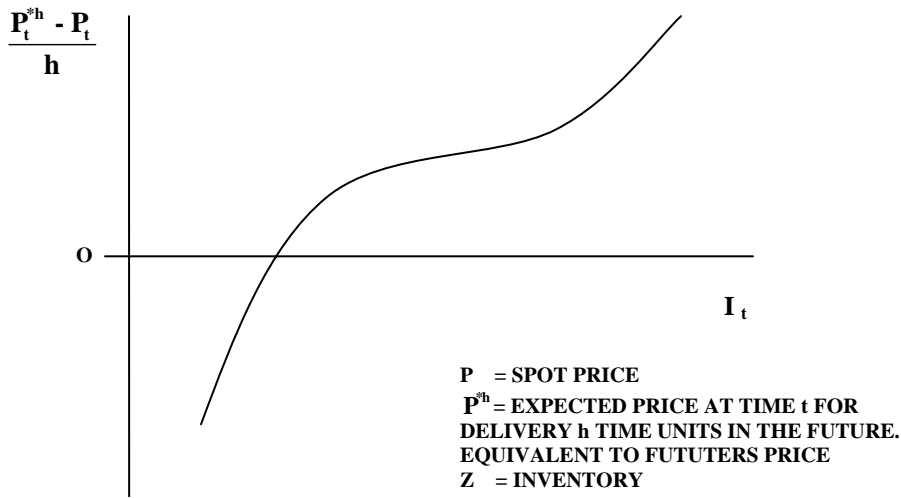
These marginal values can help to interpret the stock supply curve, since supply curves are marginal cost curves above minimum average variable costs. Differentiating the total net cost of storage thus gives the supply of storage.

$$m'_t(I_t) = o'_t(I_t) + r'_t(I_t) - C'_t(I_t)$$

The net marginal cost ( $m'_t$ ) equals the marginal storage cost ( $o'_t$ ) plus the marginal risk aversion factor ( $r'_t$ ) minus the marginal convenience yield on stocks ( $c'_t$ ). The net

marginal cost of storage need not be positive. When stocks are small,  $c'_t$  will be large. If  $c'_t$  is large enough relative to  $o'_t$  plus  $r'_t$ , the net marginal cost of storage will be negative.

**Figure 1**  
**SUPPLY OF STORAGE CURVE**



To derive the industry supply of storage curve as shown in Figure 1, market equilibrium conditions must be satisfied. The total expected net revenue from holding stocks ( $u_t$ ) is a function of the expected change in price from period  $t$  to some future period  $t+1$ . This should equal expected net total costs of storage.

$$u_t(I_t) = m_t(I_t)$$

Differentiating this equation gives the quantity of stocks that maximize expected net revenue.

$$u'_t(I_t) = m'_t(I_t)$$

This follows from the condition that expected marginal revenue equals net marginal cost. The conditions on the second derivatives of  $o_t$ ,  $r_t$  and  $c_t$  insure that the solution is a maximum.

Assuming pure competition and no external economies or diseconomies, the supply of storage curve is the horizontal sum of all individual net marginal cost function. The equilibrium level of stocks results from the demand for stocks and supply of stocks according to

$$u'_t(I_t) = EP_{t+1} - P_t$$

where  $EP_{t+1}$  is the price expected in period  $t+1$  and  $P_t$  is assumed known. For stocks which are hedged on active futures markets the price spread relevant to a decision about storage levels is the difference between a futures price and a spot price.

$$(P_t^*h - P_t)/h = f_h(I_t)$$

where  $P_t^*h$  is the futures or expected spot price  $h$  months in the future and  $h$  is the horizon time of initial expectations.

## **THE EMPIRICAL STORAGE CURVE**

The purpose of this section is to investigate the existence of supply of storage curves for aluminium, copper, lead and zinc using a cubic polynomial function to reflect the basic structure of the theoretical supply of storage curve in Figure 1. These curves with the exception of the seminal Brennan (1958) paper have rarely been observed. As indicated above, the unavailability of reliable stock data for most commodities has resulted in supply of storage analysis only being performed with surrogate variables, usually the marginal net holding cost, marginal convenience yield, or marginal physical costs. We justify the present approach because of the need to provide basic stylized facts on how inventories and spot and futures prices relate to each other in the metals industry.

Concerning recent experience, the LME (2004,p10) reports “to the extent that changes in LME inventories reflect the global pressures of demand for each metal there

will be an inverse relationship between prices and stocks.” While stock changes may be only one of several influences such as business cycles on prices, stocks do represent the basic forces that link metal supply and demand and that move markets in and out of equilibrium. What causes metal stocks to move into storage? When markets are tight, sharply rising prices can restore market balance, but they do not necessarily cause an increase or a decrease of the quantities of stocks being held. It would appear that the latter depend more on the basis or term structure of prices. Recall that *contango* represents the situation where the futures price for some horizon exceeds the spot price; in contrast *backwardation* exists when the spot price exceeds the futures price. Over most periods the LME (2004) reports that the persistence of backwardation encouraged metal to flow into LME warehouses, symptomatic of the supply of storage.

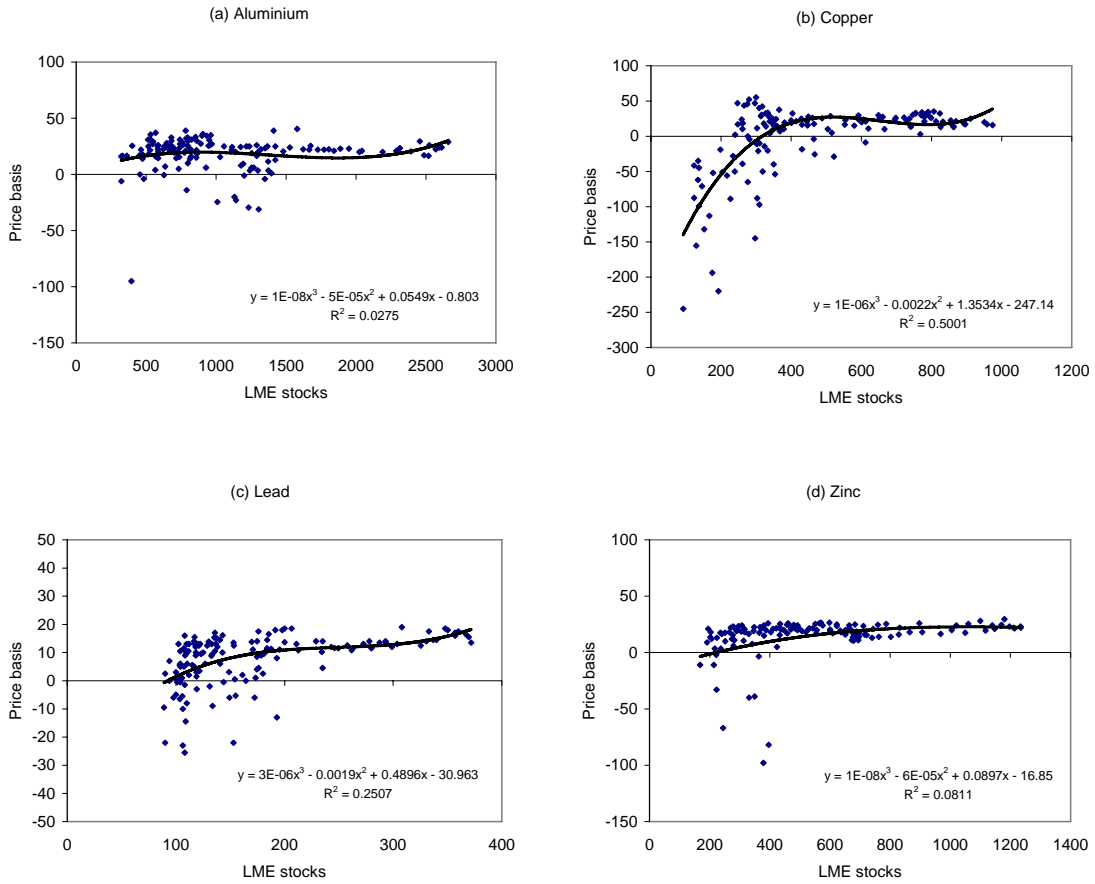
This study concentrates on inventory and price linkages in relation to the London Metal Exchange (LME) for aluminum, copper, lead and zinc. Exchange transactions are recorded in the form of spot or cash (settlement) prices and near and more distant futures prices. The price basis selected represents the difference between the 30 day LME futures contract price and the LME spot price. Pindyck (1994) has expressed concern over the choice of the exact spot price to be used for the basis and prefers the spread between two successive futures contracts. The spot price might reflect discounts and premiums between buyers and sellers or open interest in spot contracts may decline as the end of the month nears. However, the use of LME spot prices possesses the advantage that there are simultaneous spot and forward prices designated for fixed maturities and transacted every business day.

A related consideration is the selection of the stock or inventory variables to be used. Stock data are normally available on a country by country case but the evaluation of the storage curves for individual countries may not be fruitful. Instead a global analysis is performed based on the availability of such data from the World Bureau of Metal Statistics. These data measure total world stockholding and are also disaggregated into its components: LME warehouse stocks, world consumer stocks, world producer stocks and world merchant stocks. Brennan (1958) makes no such distinction in his analysis of agricultural commodities and relies on data from obvious storage such as grain elevators. In the present case, we initially examine the relation of the basis to each of the available

categories and find that LME stocks provide the best evidence of a supply of storage relationship. (Which categories do other studies use???) As with other attempts to analyse commodity stocks, reported or measured stocks are not always synonymous with actual or total stocks. The LME (2004) has compared reported stocks with official market balances for these metals and has found reasonable correlations between the two to make the present use of the reported or measured stocks credible.

Our justification of the presence of the supply of storage is not for all metals and for all categories of stock holding. Empirical illustrations of the storage curves are presented using LME stocks as an example for each of the metals in Figure 2. Copper and lead provide the most impressive confirmations while aluminium and zinc are less supportive. To provide more conclusive proof cubic polynomial functions have been estimated for each of the metals and stock categories (see Appendix 1). Consumer stocks should provide the strongest confirmation since the stock holding behaviour of consumers is closest to that specified in the supply of storage theory itself. The nonlinearities of the curve are dealt with in the estimation process by using logarithms of both variables. The basis is formed as the difference between log futures prices and log spot prices and the stock variables also are in logs. The time span of estimation is from January, 1992 to December, 2003.

**FIGURE 2**  
**EMPIRICAL SUPPLY OF STORAGE CURVES**  
**(Monthly, 1992.01 – 2003.12)**



Source: World Bureau of Metal Statistics (various issues).

Table 1 shows that the confirmation is strongest for copper, a market that experiences much greater trading interest than the others. The regression results show higher significance for the stock coefficients and adjusted correlation for total stocks, LME stocks and consumer stocks than for producers or merchants stocks. The availability of US refinery stocks also provides evidence for storage in that country. For aluminium, lead and zinc the strongest storage curves are found for LME stocks.

Because of the relatively low correlations for most of these results, the overall sample periods have been adjusted to reflect periods of activity in which the storage curve had a more pronounced confirmation. The regression results and the sample periods have been presented in Table 2. For copper most of the regression correlations remain high, except for merchant stocks. For lead, LME, consumer, and producers stocks fit better. For zinc, LME consumers and merchants stocks also fit better. No improvements were found in looking for storage curves over sub-periods. The surprisingly weak confirmation of supply of storage for these latter three metals is a stunning result. It implies that the attempts to confirm this relationship without verifying the price basis to stock correlation can be called into question.

## **COINTEGRATION AND CAUSALITY**

Given the discovered weak relationship between the price basis and inventories, it was not possible to test for the existence of causality between these two variables. Hence our quest to examine the price basis and inventory connection became one of testing the relationship between the separate cash and futures price series and inventories. To our knowledge this analysis has not been performed using cointegration and causality tests in previous studies. While Pindyck (1994) and Thurman (1988) did use data for both variables, they did not move in this direction. Only Balabanoff (1995) made such tests employing crude oil data for the U.S. market.

Our empirical tests begin with the Augmented Dickey Fuller method to test for the existence of unit roots and to identify the order of integration for each variable. This test has the advantage that it takes into account possible non-stationarity in the error process found in the ADF equation (see.....). The unit root tests are done

allowing for a constant or drift in the test specification but no time trend. Results for the tests are reported in Table 3 for the stock variables that demonstrated the best possible fit from the empirical storage analysis: total, LME and consumer stocks. As shown in Table 3, a unit root can be found for the price and stock variables but not for the basis for most of the metals. The results for aluminium are particularly poor and suggest that this metal be dropped from further analysis. Unit root tests for the residual in the corresponding cointegration equation (Engle and Granger, 1987) confirm the lack of integration and thus the possibility of cointegration exists for each of the metal equations, with the exception of.....

TABLE 3  
UNIT ROOT TESTS OF INVENTORY AND PRICE SERIES FOR  
JANUARY 1992 TO DECEMBER 2003

	ADF		PP		KPSS	
	Levels	Diffs	Levels	Diffs	Levels	Diffs
Aluminium						
Total stocks	-1.29	-8.35	-1.40	-8.48	0.58	0.15
LME stocks	-1.81	-5.74	-1.70	-5.96	0.47	0.11
Consumer stocks	-2.08	-10.13	-2.39	-14.52	0.54	0.19
Spot price	-2.26	-12.25	-2.31	-12.25	0.16*	0.06
Futures price	-2.10	-11.78	-2.24	-11.78	0.15*	0.08
Price basis	-6.51		-6.61		0.81*	0.11
Copper						
Total stocks	-3.19*	-11.91	-2.78	-17.63	0.62	0.07
LME stocks	-1.93	-8.09	-1.91	-7.24	0.71	0.07
Consumer stocks	-2.50	-12.58	-3.73*	-20.12	0.29*	0.09
Spot price	-1.69	-12.01	-1.79	-12.02	0.79	0.12
Futures price	-1.64	-11.52	-1.81	-11.55	0.82	0.12
Price basis	-3.41		-4.51		0.26	
Lead						
Total stocks	-1.41	-14.56	-1.56	-14.61	0.29*	0.28
LME stocks	-1.55	-7.56	-1.76	-8.01	0.40*	0.11
Consumer stocks	-2.44	-13.00	-2.38	-13.36	0.24*	0.10
Spot price	-1.47	-10.44	-1.68	-10.45	0.29*	0.16
Futures price	-1.38	-10.02	-1.66	-10.06	0.32*	0.15
Price basis	-5.68		-5.68		0.20	
Zinc						
Total stocks	-1.29	-10.29	-1.51	-10.32	0.29*	0.31
LME stocks	-2.86	-4.30	-2.26	-7.42	0.30*	0.29
Consumer stocks	-1.72	-14.40	-1.48	-14.63	0.43*	0.18
Spot price	-2.09	-11.82	-2.27	-11.84	0.55	0.06
Futures price	-1.94	-12.74	-2.17	-12.75	0.57	0.06

Price basis	-4.69		-5.26		0.14	
1% critical value	-3.47	-3.47	-3.47	-3.47	0.74	0.74
5% critical value	-2.88	-2.88	-2.88	-2.88	0.46	0.46

*Notes*

- Levels and Diffs denote that the statistics are based on logarithmic levels and first differences respectively. Price basis is the futures price minus the spot price, where both variables are measured in levels.
- ADF is the Augmented Dickey Fuller (Dickey and Fuller, 1981) unit root test. The ADF regression includes an intercept term and the lag length of the ADF test is determined by minimising the SBIC.
- PP is the Phillips and Perron (1988) unit root test.
- KPSS is the Kwiatkowski et al. (1992) unit root test.

The simple cointegration results presented above need to be further elaborated in order to provide a suitable test to determine whether any causality exists between the metal stock and price variables. We have chosen the Johansen (1995) method that implements VAR-based cointegration tests when a group of non-stationary series are under examination. Johansen's method tests the restrictions imposed by cointegration on the unrestricted VAR involving the series with  $p$  terms.

$$y_t = A_1 y_{t-1} + \dots + A_p y_{t-p} + Bx_t + \varepsilon_t,$$

where  $y_t$  is a  $k$ -vector of non-stationary I(1) variables,  $x_t$  is a  $d$  vector of deterministic variables, and  $\varepsilon_t$  is a vector of innovations. We can rewrite the VAR as:

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t,$$

where

$$\Pi = \sum_{i=1}^p A_i - I_k, \quad \Gamma_i = - \sum_{j=i+1}^p A_j$$

Granger's representation theorem asserts that if the coefficient matrix  $\Pi$  has reduced rank  $r < k$ , then there exist  $k \times r$  matrices  $\alpha$  and  $\beta$  each with rank  $r$  such that  $\Pi = \alpha\beta'$  and  $\beta'y_t$  is stationary.  $r$  is the number of cointegrating relations (the cointegrating rank) and each column of  $\beta$  is the cointegrating vector. The elements of  $\alpha$  are known as the adjustment parameters in the vector error correction model. Johansen's method is to estimate the  $\Pi$  matrix in an unrestricted form, then test whether we can reject the restrictions implied by the reduced rank of  $\Pi$ .

By examining the  $\Pi$  matrix, we can detect the existence of cointegrating relations among the  $Y$  variables. The most interesting case is  $0 < \text{rank}(\Pi) < p$ . This implies that there are  $r$  cointegrating relations among the elements of  $Y_t$ , and there are  $p \times r$  matrices  $\alpha$  and  $\beta$  such that  $\Pi = \alpha\beta'$ . Hence  $\alpha$  is a matrix of error correction parameters and  $\beta$  is interpreted as a matrix of cointegrating vectors, with the property that  $\beta'Y_t$  is stationary even though  $Y_t$  itself is not stationary.

The results of the cointegration tests are reported in Table 4.  $T^*$  and  $C^*$  are test statistics and critical values for the null  $H_r^*$ : with at most  $r$  cointegrating vectors but no linear trend.  $T$  and  $C$  are test statistics and critical values for the null  $H_r$ : with at most  $r$  cointegration vectors and a linear trend. We conclude that there is one cointegration vector because the trace test rejects both the null hypothesis of zero cointegration rank and the null of at most one cointegration rank with no linear trend, but it does not reject the null of at most one cointegration rank with a linear trend.

Table 4  
Johansen cointegration tests: Spot price, futures price, stocks

Null Hypothesis	Trace test			Max-eigenvalue test		
	LME	Consumer	World	LME	Consumer	World
<b>Aluminium</b>						
$r = 0$	42.26	39.42	48.78	18.15	28.45	20.97
$r = 1$	24.11	10.96	20.84	12.86	6.61	14.07
$r = 2$	11.25	4.34	6.95	11.25	4.34	3.76
<b>Copper</b>						
$r = 0$	37.32	53.08	39.69	20.22	41.17	25.49
$r = 1$	17.10	11.91	14.20	13.38	8.77	11.07
$r = 2$	3.72	3.14	3.14	3.72	3.14	3.14
<b>Lead</b>						
$r = 0$	54.37	37.07	47.55	44.10	29.22	31.92
$r = 1$	10.26	7.84	15.63	6.63	4.93	10.59
$r = 2$	3.63	2.91	5.03	3.63	2.91	5.03
<b>Zinc</b>						
$r = 0$	51.16	67.01	61.06	39.54	56.03	52.50
$r = 1$	11.61	10.98	8.56	6.46	8.15	5.45

$r = 2$	5.14	2.83	3.11	5.14	2.83	3.11
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*Notes*

- Trace test, 5 per cent critical values:  $r = 0$ , 29.68;  $r = 1$ , 15.41;  $r = 2$ , 3.76.
- Max-eigen test, 5 per cent critical values:  $r = 0$ , 20.97;  $r = 1$ , 14.07;  $r = 2$ , 3.76.

The presence of cointegration dictates that one not employ the standard Granger causality test (Granger, 1988). Instead we employ a vector error correction model (VECM) that also permits an interpretation of the short run and long run equilibrium dynamics. In essence we take the above VAR model into a VECM model, where the cointegrating errors from the Johansen model become the error correction variables for the Engle and Granger VECM given below.

$$\Delta Y_{it} = \mu_{it} + \beta' ECT_{t-1} + \sum_{i=1}^m a_i \Delta Y_{1,t-i} + \sum_{i=1}^m b_i \Delta Y_{2,t-i} + \sum_{i=1}^m c_i \Delta Y_{3,t-i} + \sum_{i=1}^m d_i \Delta Y_{4,t-i} + \varepsilon_i,$$

where  $Y_{it}$  denotes inventories, cash prices or futures prices and  $\beta' ECT_{t-1}$  contains  $r$  cointegrating terms, reflecting the long-run equilibrium relationship among variables. From the system, the Granger-causality tests are examined by testing whether all the coefficients of  $\Delta Y_{2,t-i}$ ,  $\Delta Y_{3,t-i}$ , or  $\Delta Y_{4,t-i}$  are statistically different from zero as a group based on a standard F-test and/or whether the  $\beta'$  coefficient of the error-correction term is also significant. (How was lag length picked???)

Table 6  
Granger causality tests

	Source of causation				
	Short run		Long run		
	$\Delta$ Stocks	$\Delta$ Cash price	ECT	ECT/ $\Delta$ Stocks	ECT/ $\Delta$ Cash price
<u>Aluminium</u>					
$\Delta$ LME		5.07*	4.19*		5.79*
$\Delta$ Cash price	4.19*		14.35*	7.53*	
$\Delta$ Consumer		0.20	0.69		0.42

ΔCash price	5.54*		12.92*	7.32*	
ΔWorld		6.30*	8.14*		8.53*
ΔCash price	5.28*		13.71*	7.58*	
<u>Copper</u>					
ΔLME		0.16	6.28*		2.38**
ΔCash price	5.98*		6.30*	6.42*	
ΔConsumer		1.25	7.95*		3.63*
ΔCash price	2.44**		1.58*	2.02	
ΔWorld		0.32	0.48		0.35
ΔCash price	2.22		2.50	2.40**	
<u>Lead</u>					
ΔLME		0.21	2.38		0.84
ΔCash price	1.51		22.36*	10.25*	
ΔConsumer		1.69	1.42		1.80
ΔCash price	0.07		15.03*	5.11*	
ΔWorld		1.16	0.23		0.79
ΔCash price	0.15		21.46*	7.17*	
<u>Zinc</u>					
ΔLME		0.67	12.52*		4.44*
ΔCash price	6.32*		10.58*	9.39*	
ΔConsumer		0.04	1.16		0.42
ΔCash price	2.25*		1.71	2.10*	
ΔWorld		0.02	2.05		0.81
ΔCash price	3.56*		5.42*	3.68*	

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\* Significant at the 5% level.

\*\* Significant at the 10% level.

## CONCLUSIONS

## Appendix 1

**Table 1**

### **SUPPLY OF STORAGE REGRESSIONS**

	Aluminium	Copper	Lead	Zinc
Constant	-0.803 (-0.03)	-247.14 (-8.21)	-30.96 (-1.67)	-16.85 (-0.62)
LME	0.05 (0.83)	1.35 (6.09)	0.49 (1.73)	0.09 (0.57)
LME <sup>2</sup>	-0.01 (-0.97)	-0.01 (-4.60)	-0.01 (-1.50)	-0.01 (-0.25)
LME <sup>3</sup>	0.01 (1.10)	0.01 (3.76)	0.01 (1.45)	0.01 (0.11)
R <sup>2</sup>	0.03	0.50	0.25	0.08
DW	0.95	1.04	1.01	0.71

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## Appendix

### DEFINITIONS OF STOCK AND PRICE VARIABLES

awuns = unwrought world stocks (nonwms source)  
almes = LME exchange stocks  
ausuns = unwrought us stocks (nonwms source)  
ausis = US ingot stocks  
auiis = US scrap stocks  
ausits = US total stocks or approximately usis+usiss+all other  
awcons = world consumer stocks  
awmers = world merchant stocks  
awoths = world others stocks or wcons+wpros+wmers  
awpros = world producers stocks  
awtots = world total stocks or lmes+woths

#### Copper

clmes = LME exchange stocks  
ccmxs = COMEX stocks  
cnusrs = Non-US refined copper stocks  
curs = US refined copper stocks  
cwcons = world consumer stocks  
cwmers = world merchant stocks  
cwoths = total country stocks, or wcons+wpros+wmers  
cwpros = world producers stocks  
cwtots = world total commercial stocks or lmes+woths

#### Lead

llmes = LME exchange stocks  
lusrs = US refined lead stocks  
lwcons = world consumer stocks  
lwmers = world merchant stocks  
lwoths = total country stocks, or wcons+wpros+wmers  
lwpros = world producers stocks  
lwtots = world total commercial stocks or lmes+woths

#### Zinc

zlmes = LME exchange stocks  
zusps = US slab refined zinc primary producers stocks  
zwcons = world consumer stocks  
zwmers = world merchant stocks  
zwoths = world others stocks or wcons+wpros+wmers  
zwpros = world producers stocks  
zwtots = total country stocks, or wcons+wpros+wmers

alcp, cucp, lecp, zncp = LME cash price for aluminum, copper, lead and zinc.

alfp, cufp, lefp, znfp = LME near futures price (30 day) price for aluminum, copper, lead and zinc.

Alfp2, cufp2, lefp2, znfp2 = LME near futures price (30 day) price for aluminum, copper, lead and zinc.