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A Test of the Efficiency of the Aluminium and
Copper Markets at the London Metal Exchange*

by
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1. Introduction

In a futures market hedgers can secure a certain price for a commodity at a future delivery date. The futures price also conveys information about the cash price at the maturity of the futures contract in that it reflects the different cash price expectations of the market participants at the time of contracting. Such information will be particularly important for agents not fully hedged as well as for market participants planning for future production or use. This paper will concentrate on information aspects of futures prices and will disregard the security trade aspect.

In the futures market, prices are created via the balancing of supply and demand which themselves are contingent upon the information currently underlying the market process. This knowledge consists partly of past prices from the same market, so that the new prices becomes part of subsequent information sets. In this sense, trading on futures markets (as on markets in general) can be viewed as an information producing activity. Through arbitrage possibilities over time, the futures price and the spot price of any storable commodity are related to each other by the carrying charge. Thus futures markets also generate information about future spot prices. In this respect, futures models compete with econometric forecasts of future spot prices derived from markets which are based on estimated structural or statistical relationships.

Taking copper and aluminium (which received little attention up to now) as examples this paper seeks to test the predictive performance of the futures market at the London Metal Exchange (LME) against models of price formation. The literature on futures market efficiency with special reference to aluminium and copper is reviewed in chapter 2. The third chapter contains a description of LME procedures and its role in international copper and aluminium trade, while chapters 4 to 6 are devoted to the tests: presentation of the data basis (4), model selection and specification (5) and results (6). Conclusions are drawn in chapter 7.

2. Previous Studies on Futures Market Efficiency

An extensive literature covers various procedures for testing the efficiency of futures markets for a variety of commodities. Some of the research addresses the copper markets but the aluminium market has not been considered yet to the author's knowledge. Basically, the literature has come to distinguish weak form and semi-strong form tests of the efficiency of futures markets (Fama, 1970). The former generally centres upon the past spot and futures prices of the analyzed commodity as currently available information which has to be "fully reflected" in the prices if the market is efficient. If the information set considered for the market includes other publicly available information as well (e.g. the price movements for other commodities), the test is called a semi-strong form test.

In weak-form efficient markets, any speculative position using only the present day information set would yield no extra-normal profits. Tests of the weak form efficiency rely usually on investigating the dependence of current prices on past prices (as the underlying information set). A frequently used method involves the testing of the random walk hypothesis for the time series of prices (e.g. Labys et al., 1971; Leuthold, 1972; Cargill and Rausser, 1975).

Another weak-form approach (e.g. Tomek and Gray, 1970; more recently Goss, 1981) focuses on the equation

$$A_t = a + bF_{t-i} + U_t$$

where A_t is the spot (actuals) price, F_{t-i} is the futures price in $t-i$ with i months to maturity and U_t a stochastic error term. Coefficients of 0 for a and 1 for b then would render the futures price an unbiased predictor of the subsequent cash price, and hence would exclude systematic profits from persistent speculative positions. Employing a similar method, Kolb and Gay (1983) find the futures market for live cattle an unbiased predictor of the subsequent spot price. This line of reasoning recently has been attacked (Burns, 1983) by arguing that during the time elapsed between closing futures contract and its maturity new information regularly will have emerged and to the extent that the futures prices incorporate premiums, their valuation will have changed. Thus there will usually be wide discrepancies between current futures prices and the later spot prices, so that running a regression of spot prices on future prices will not provide an appropriate test of efficiency.

Semi-strong tests of market efficiency form the second group of studies. The crucial test hinges on whether futures prices fully incorporate all publicly available information at the time of contracting. In attempting to approximate the "publicly available information", two different approaches have been employed. The first one (e.g. Leuthold and Hartmann, 1979; Gupta and Mayer, 1981) uses an econometric model of the market under study and compares the forecasting error of the model with that of futures prices. The models are reestimated for every new observation added to ensure the same information set for the model and futures markets. Whereas Leuthold and Hartmann (1979) are somewhat inconclusive on the efficiency of the hog market, Gupta and Mayer (1981) find no significant evidence for inefficiency of the copper, tin, sugar, cocoa and coffee markets^{1,2}.

The second approach in testing the semi-strong form of market efficiency assumes that the forecasting errors for closely related products yield all the relevant publicly available information (Goss, 1982). If the market for a particular good is semi-strong efficient, then - according to this approach - the forecasting errors for this good must be uncorrelated with those for the other commodities. Goss'

¹ Choksi (1984) in her study of the LME copper market concentrates on determinants of the difference between the spot and future price of copper, but doesn't present statistically tested results.

² One can also assume that the informations available to professional forecasters represent all there is to know in the market. With this hypothesis, futures market did on average better than four major commercial forecasting agencies and the USDA in predicting the future cash prices for agricultural commodities (Just and Rauser, 1981).

results indicate that the hypothesis of efficient copper, tin, lead and zinc markets should be rejected. However, since every period brings new information, it may well be that each innovation is simultaneously considered relevant by the traders for all metal markets. Then the prices for the different metals would be affected in the same way, and we would observe a strong correlation between the forecasting errors in these markets. So, although the prices might fully reflect all information publicly available at the time of contracting, the hypothesis of market efficiency would wrongly be rejected.

But Goss justly underlines the importance of other metal prices for any particular metal market. With respect to substitutability, aluminium is the metal which competes most closely with copper for use in a variety of applications¹. Therefore it seems most appropriate to include aluminium data in the information set for copper, and vice versa. A model which takes into account for both markets the price movements of copper as well as of aluminium should yield more accurate price forecasts than a model based on the prices of just one metal. Before presenting such a wider time series model and testing its predictive performance against that of futures markets, the next chapter gives details on the trading practices at the LME relevant to data selection and model building.

¹ Habig (1983) gives details on technical characteristics of conductor copper and aluminium, and on several estimates of short and long run elasticities of substitution between the two metals (values between 0.24 and 6.30). The data bases for the studies cited there just reach to the mid sixties; substitution might have become even easier since.

3. Copper and Aluminium Trade at the LME

Copper and aluminium are traded on spot and futures markets at the London Metal Exchange and the Commodity Exchange, New York (COMEX). Due to excellent possibilities of arbitrage in standardized contracts, prices are virtually the same (Wagenhals 1984). Although COMEX offers a wider range of maturity ranges (up to 14 months ahead instead of usually three months ahead at the LME), the LME is generally considered the more important exchange with respect to turnover, physical delivery and price signalling (e.g. Radetzki, 1983; Brisk, 1984). LME's position in world copper trade has been strengthened after CIPEC¹ attempts to control the copper price finally failed in the mid sixties, and it was the first exchange to trade in aluminium futures (1978). Trading takes place between members (principals market)²; the principals concept seems to be appealing particularly for the trade, such that e.g. three quarters of all LME business in aluminium stems from the trade, as compared to less than a fifth at the COMEX (Brisk, 1984). No regulatory agency monitors the trading or even intervenes. There are no floors or

¹ The council of copper exporting countries consists of Chile, Peru, Zambia, Zaire and Indonesia as full members.

² The exchange members usually act on behalf of clients. The physical quantities marketed on the cash market are relatively small in comparison to the trade volume in the futures market. The physical exchange is mainly utilized by large producers selling small quantities, small producers selling production in excess of existing contract requirements, and fabricators selling excess stock. On the demand side we find customers desiring to make marginal adjustments to the extent and the composition of their stocks, e.g. by using the exchange as an "instant refinery" (Labys et al., 1971).

ceilings on price variations or on open positions a single agent is allowed to hold. All this indicates little interference from non-market forces.

Procedures matter for market efficiency, thus a brief description is called for. The exchange opens at noon with the first trading round consisting of several five-minutes intervals ("rings") in each of which one metal is traded only. The first ring in both rounds is devoted to copper whereas the other metals, among them aluminium, are dealt with in a different sequence. The closing quotations of the second round for cash, three months and settlement are the official prices of the LME¹. This arrangement of trade sequences implies a certain chronological order in which prices are created and transmitted to the public; the order will be relevant for the time structure of the forecasting model.

Three months contracts are continuously traded, hence there are as many maturity dates as there are working days at the exchange. After the date of contracting, a contract still can be transacted but prices are quoted just unofficially (Goss, 1982)².

¹ A three member fixing committee agrees upon the price quotation, which can be challenged by any exchange member if he feels that it does not reflect the session. Hence the price quote is the consensus of opinion by the exchange members.

² This constitutes a major difference to COMEX in that this exchange bundles the contracts to a certain number of specified delivery months. Unofficially, contracts with maturity lengths other than 3 months are traded too; furthermore, trade takes place also before and after each session (v. Armin, 1979).

Long-term contracts are based on LME prices via some 'formulas' in the case of copper (Banks, 1974; Radetzki, 1983), and similarly for aluminium (Brisk, 1984). The LME is thus linked to trade in both metals which never actually touches the metal exchange. This broadens the market enormously so that the assumption seems justified that also fairly large, not just marginal, quantities can change hands at the LME prices, even after these had been established. The width of the market then enables all market participants to use the LME prices in their considerations and this underlines their need to obtain as accurate price forecasts as possible¹.

4. The Data Base

For a time series analysis of prices the data should be as little aggregated over time as possible. First, aggregated data would have to be identified with the end of the time interval over which aggregation has taken place, since otherwise, the aggregated price could unrealistically supply information about the future course of the events. But even if this is not the case, aggregated prices would not reflect the knowledge on relative scarcity as it is at the end of the aggregation period: Trading probably would not take place at these prices. Secondly, aggregation of even uncorrelated data can lead to spurious autocorrelation in the series which would misrepresent the statistical nature of

¹ This applies also if averages of prices are used for the development of trade rules, rather than single quotations.

the process and thus would induce a misspecified model (Chatfield, 1975).

The data base consists of daily unaveraged LME prices for copper and aluminium, as from the end of the second trading round. They refer to higher grade cathodes (copper) and primary ingots of 99.5 % minimum purity (aluminium) in pounds sterling per metric ton¹, cash and 3 months forward. Since both metals are traded continuously at LME, the data on futures always belong to contracts for delivery in exactly 3 months' time. This enables us to abstract from valuation problems associated with varying contract lengths, as with COMEX data. The observations range from the first trading day in 1983 till the last trading day in September 1984, yielding a total of 439 observations for each variable.

5. The Model

The efficiency of the copper and aluminium futures market at the LME will be tested by comparing the predictions of a model of price formation with those implied by the futures markets. The model selection therefore forms a crucial step in the testing procedure since it defines the competitor of the futures market in this comparison. The narrower the class of models under consideration, the more difficult it

¹ Pounds sterling can easily be converted into, say, U.S. dollars via efficient foreign exchange markets. Recent evidence of efficient foreign exchange markets is presented for a variety of currencies by Huang (1984) and Sanderson (1984).

would be to reject the hypothesis of market efficiency as the number of alternative models and their potential for accurate predictions is diminished. On the other hand, the choice within a wide range of models should be guided not by forecasting performance, since this would be an ex-post decision and would bias the test in favour of rejection of the efficiency hypothesis. Rather, the selection decision is based on statistical criteria of the model's ability to absorb the information incorporated in the available data, e.g. the Box-Pierce and the adjusted goodness-of-fit statistic. These statistics report on the randomness of the model residuals and their relative weight in accounting for the overall variation in the data. Also, model selection should only use information available up to the beginning of the forecasting period in order to simulate as closely as possible the decision problem a market participant would be facing.

If the class of models chosen for this paper is actually used in practice, this adds to the credibility of the testing approach. Here, autoregressive integrated moving average models were chosen, as frequently in practical forecasting (Taylor, 1983)¹. When using ARIMA or other regression models, the assumption is implicitly made that all information relevant in the market process is contained in the prices -

¹ Different forecasting methods will probably be used by different agents; divergent beliefs then stimulate trade. But competition among forecasting methods possibly eliminates one or another approach. Time series analytical tools are frequently also used in reports on commodity price cycles published in "Cycles", e.g. Dewey (1974).

otherwise safe gains could be realized¹. On the other hand this implies that the sequence of prices available as the data base is assumed to originate from an economic structure which will basically remain unchanged henceforth. In this respect, ARIMA models are only as restrictive as any other econometric model².

The model which was chosen to represent the information contained in the data was a simultaneous model of the copper and the aluminium prices consisting of two equations:

$$x_t + a_1 x_{t-1} + a_2 x_{t-2} + c_1 y_t = u_{1t}$$

$$y_t + b_1 y_{t-1} + b_2 y_{t-2} + d_1 x_t = u_{2t}$$

where x_t and y_t are the copper and aluminium prices, respectively, and u_{1t} and u_{2t} represent purely random error terms which are uncorrelated with lagged values of each other. This model was identified in the much wider class of vector autoregressive models by employing several checks³. First,

¹ This is not an assumption that leads to circular reasoning, since the test addresses the question whether the information is efficiently used.

² ARIMA-forecasts are contingent on the information set as at the day the prediction is made and on the structure identified so far. Forecasts with autoregressive models containing exogenous variables depend additionally on time paths explicitly specified for all exogenous variables. But any particular given time path would be of little help in testing market efficiency.

³ The raw data were judged stationary after an inspection of a plot of the two price series as well as of the auto- and cross-correlation functions. In view of the large data base, the Jackknife estimation method for the autocorrelation coefficients was not employed, since the bias of

it has been investigated whether in the first equation relating to copper prices, the aluminium price of several days ago played a significant role, and whether some lagged copper price had a significant influence on aluminium prices (overfitting). Neither could be found. Secondly, the error term structure was looked at. There were various degrees of moving averages fitted to the model, but none proved significant¹. Throughout the principle of parsimony in adding more autoregressive or moving average terms to the equations has been followed. Thirdly, it was tried to use the first differences of the data instead of their absolute levels. This procedure can be meaningful if the raw data show signs of non-stationarity, e.g. by an underlying trend in the prices. However, using the day-to-day changes in prices led to fairly low significance levels for the coefficients, together with non-randomness of the residuals, a usual indication of an overdifferenced data set. The random walk hypothesis was also tested by setting a_1 and b_1 equal to 1 and all other coefficients to zero. The restriction on the coefficients a_1 and b_1 had to be rejected, furthermore it turned out that

the order $1/N$ would be very small. However, for a model used later, a test on structural change was performed (Chow-test) with the sample split into two equal halves to check whether the underlying probability distribution changed. No evidence was found to support this hypothesis.

¹ When looking at the values of an autocorrelation function for a large number of lags, as is possible with a large data set, some "significant" autocorrelation at higher lags may occur. One could account for this data feature (thus improving the Box-Pierce statistic considerably) by adding suitable moving average terms to the equation. However, with a significance level of 5 percent, still 5 out of 100 autocorrelation coefficients calculated from the sample could easily be significantly different from zero even if the underlying process is white noise in reality.

the residuals from fitting the random walk model did not exhibit the behaviour of a white noise (purely random) process as should be¹.

For comparison purposes, two slightly different models were also considered. They are distinguished from the above model (model 1 in Table 1) by more restrictive specifications: model 2 assumes no direct influence of the respective other metal's contemporaneous price (that means c_1 and d_1 are set to zero) but allows as before for a relationship between the copper and the aluminium price through the error term. Thus, both markets are only seemingly unrelated. In model 3 even this link between the two markets is cut, so that the price movements on these two markets are modelled separately by second-order autoregressive equations.

For the following forecasting procedure, the models were estimated with the initial data base as information set (results in Table 1). Then, the models were reestimated each time new information was added. The updating procedure was necessary for the theoretical reason outlined above that the models must be provided with as recent informations as the competing futures markets. The methods used for estimating the three models were "three stage least squares", Zellner's "seemingly unrelated regression" with the simultaneity work-

¹ Gupta and Mayer (1981) found a first-order autoregressive process to appropriate formulation for weekly data. This suggests that the informative content of prices dating two weeks back is negligible, which is not the case with prices two days old. However, Gupta and Mayer report no formal test of the random walk hypothesis.

Table 1 - Regression Results for Second Order Autoregressive Models

Variable ⁽¹⁾	Model 1		Model 2		Model 3	
	Copper	Aluminium	Copper	Aluminium	Copper	Aluminium
Const.	56.6 (3.94)	32.6 (2.00)	24.1 (2.51)	11.48 (2.06)	24.1 (2.10)	24.2 (3.64)
x_t		-0.007 (-0.57)				
x_{t-1}	0.874 (18.4)		0.893 (18.7)		0.877 (16.0)	
x_{t-2}	0.093 (1.97)		0.084 (1.77)		0.101 (1.85)	
y_t	-0.023 (-3.56)					
y_{t-1}		0.856 (18.2)		0.872 (18.4)		0.851 (15.7)
y_{t-2}		0.120 (2.58)		0.117 (2.50)		0.125 (2.34)
$\sigma(u_1, u_2)$ ⁽²⁾	0.572	0.572	0.558	0.558		
\bar{R}^2 ⁽³⁾	0.96	0.98	0.96	0.98	0.96	0.98
DW ⁽⁴⁾	2.03	2.03	2.01	2.04	1.98	2.02
BP ⁽⁵⁾	40.1	37.0	39.6	37.1	39.8	37.5
Sign. ⁽⁶⁾	0.92	0.96	0.93	0.96	0.93	0.96

(1) x_t and y_t refer to the prices of copper and of aluminium, respectively. (2) Correlation between the error terms in each equation. (3) Adjusted R^2 . (4) Durbin-Watson statistic. (5) Box-Pierce statistic, distributed as Chi-square with 54 degrees of freedom, calculated as the sum of squared autocorrelation coefficients (up to a previously specified maximum lag) times the number of observations. (6) Sign. denotes the significance level reached in testing the hypothesis of white noise residuals.

ing through the common covariance structure of the error terms u_1 and u_2 , and ordinary least squares, respectively. From the Durbin-Watson statistic given in this table it can be seen that for all specifications a first order autocorrelation of the residuals can be excluded safely. Turning to higher order autocorrelation in the residuals, the Box-Pierce statistic shows a fairly high confidence level for the hypothesis of white noise¹. The 95 percent level has been missed slightly for the copper equations whereas the probability that the residual process is not purely random is less than 5 percent for aluminium. One could think of respecifying the aluminium equation of the first model and to ignore the influence of the copper price on the price for aluminium due to its low statistical significance. But this would lead to a recursive model, where the prices for aluminium would influence those for copper but not vice versa. However copper is traded first, before aluminium is traded, so that such a formulation would seem implausible. Thus, in view of the information on the properties of the residual series related by the statistical measures and considering the a priori knowledge on trading practices at LME, the simultaneous equation model of price formation with two lagged variables appears appropriate².

¹ Since the Box-Pierce-statistic can depend quite sensitively on the maximum number of lags considered, this number has been specified for all estimations in advance as the minimum of $N/2$ and $3\sqrt{N}$, with N as the number of observations, to avoid arbitrariness.

² The model does not purport to be an economic model in the sense that it consists of a set of behavioural equations. Under the assumption that new information will shift the demand and supply relationships it appears very difficult

6. The Model's Forecasting Performance Relative to Those of the Futures Market

For every model, the spot prices were forecasted exactly three months ahead for 38 consecutive days. Every model prediction did not completely tally with the corresponding actual spot price in three months time, so that a prediction error was made. Taking the futures prices as forecasts of future spot prices, a prediction error resulted as well. The information embedded in the prediction errors had to be condensed to a single measure to evaluate the relative forecasting performance of the models and the futures market. We choose a quadratic function of the errors, the mean squared error, to represent the loss in accuracy associated with predicting, since it gives a greater weight to large errors be they positive or negative¹.

Table 2 reports the mean squared forecast error (MSE) for the period considered when either the futures market or a time series model is taken to generate the forecasts. For each model, the hypothesis is tested that the MSE resulting from the model forecasts and the MSE resulting from the

to estimate these relationships econometrically with any observation generated in a different information environment. The main focus here is on the statistical absorption of the information contained in the price series. Therefore, the variables hardly have economically meaningful coefficients, and an interpretation will not be attempted here. Specifically the negative signs for the aluminium price in the copper equation and vice versa might put the substitutive character of the two metals into question, but since demand functions are not explicitly modelled, one cannot infer a complementary relationship.

¹ This implies risk averse preferences on the part of the average market participant.

futures markets forecasts could originate from probability distributions with same means. If any model MSE is significantly lower than futures market MSE, then the hypothesis of market efficiency must be rejected¹. As the results in Table 2 show, the time series models forecast the spot price of copper and aluminium in most cases not as accurately as the futures markets did. Only models 2 and 3 had a lower MSE for copper than the LME market for copper futures; but these differences were not statistically significant. Thus, the hypothesis of market efficiency cannot be rejected at the 95 percent confidence level for either the aluminium or for the copper market. In the case of aluminium, the tests rather suggest that the futures market yields distinctly more accurate price forecasts than the autoregressive models employed. This means that although the models absorbed sufficiently the information contained in past prices, the study of the futures markets provided a far better knowledge of the future course of aluminium prices than did the models. It may be noted that the second model (seemingly unrelated equations) performs relatively best for both commodities, though not much different from the other models' performance.

The ratio of root mean squared error and absolute error in Table 2 suggests that there are no outliers in the forecasting errors, since they would drive the ratio up. So the result may be stated that with no model prediction being wildly wrong, the futures markets perform on average at

¹ As the price of the main substitute is contained in the information set, this constitutes a semi-strong form test.

Table 2 - Mean Squared Error and t-Value for Evaluating the Predictive Performance of Three Models Relative to that of Corresponding Futures Markets

	Copper			Aluminium		
	MSE ⁽¹⁾	t ⁽²⁾	$\frac{RMSE}{AE}^{(3)}$	MSE ⁽¹⁾	t ⁽²⁾	$\frac{RMSE}{AE}^{(3)}$
Futures market	539.4	-	1.13	12782.1	-	1.07
Model 1	551.6	0.09	1.20	24380.9	7.67	1.02
Model 2	432.2	1.00	1.27	23518.1	7.24	1.03
Model 3	438.7	0.93	1.27	24023.0	7.46	1.02

(1) The mean squared error (MSE) is calculated as $\frac{1}{N} \sum_{t=1}^N (M_{t-i} - S_t)^2$, where M_{t-i} is the model forecast of the spot price for period t, calculated i periods ago, and S_t is the spot price.

(2) The t-value is calculated to test whether the probability distributions of futures market and model forecast errors have the same mean:

$|t| = \sqrt{n} |MSE(mod.) - MSE(f.m.)| / \sqrt{Var(SE(mod.) - SE(f.m.))}$
where SE denotes squared (forecasting) error and Var(.) the estimated variance. The 5 percent significance level of t (with 40 degrees of freedom) is 1.684. (3) RMSE/AE is the ratio of root mean squared error (\sqrt{MSE}) and absolute error.

least as good as - and in the case of aluminium even clearly better - than the models which incorporate sufficiently all information publicly available at the time the futures contracts were closed.

7. Summary and Conclusion

The paper reports a semi-strong test of the efficiency of the copper and aluminium markets at the London Metal Exchange. The test consists of a comparison of the predictive powers of the futures market and of a suitable forecasting

model of prices. As copper and aluminium are rather close substitutes, the model took the relatedness of the copper and aluminium markets into account. For this, three alternative specifications with a varying degree of simultaneity in prices were constructed. The class of models considered here to compete against futures markets were of the vector autoregressive moving average type. The model incorporated sufficiently all publicly available information to render the ensuing test on market efficiency in the semi-strong form meaningful. Testing the randomness of the residuals from fitting the model proved to be an appropriate means to warrant sufficient exploitation of the information contained in the prices, which were assumed to incorporate the effects of all market relevant factors.

The tests show that according to the criterion "mean squared error", the models did not perform better in a statistically significant way. Thus, the hypothesis of efficient copper and aluminium markets cannot be rejected on the evidence of the tests. Futures markets provide at least as good a basis for anticipating the future course of cash prices as a model even if it exhausts the information commonly used. Since the model was determined from as wide a class as possible, the result of this test gives the market efficiency hypothesis an even broader basis. This sheds further light on the superior information processing capability of futures markets.

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