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ALUMINIUM MARKET AND THE MACROECONOMY

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Abstract

We propose and test a structural model of the interaction between the aluminium market and the macroeconomy incorporating the rational expectations hypothesis. Based on a competition *à la* Cournot, our model predicts that aluminium spot price and inventories will respond to macroeconomic shocks to line up supply to the demand level. The model also includes incomplete adjustments to shocks that occur near the delivery date of futures contracts with the implication of a likely high persistence in the aluminium spot price.

Estimation results show that the aluminium price is significantly affected by the real exchange rate, while the influence of the real interest rate is small. We argue that this result is largely expected once we consider the peculiar features of the aluminium market. Further support to this view is provided by the large persistence of the aluminium price response to its own shock and by the negligible contribution of stockholdings innovations to the price forecast error variance. Finally, macroeconomic shocks explain on the whole a relevant share of the aluminium market variables forecast error variance.

JEL classification: L11, D84, C32.

Key words: Metal commodities, Monetary transmission mechanism, Rational Expectations Hypothesis test, SVAR.

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I. Introduction

In this paper we study the effects of monetary policy and other relevant macroeconomic shocks on the dynamics of the world aluminium market price and stockholding activities. The adjustment of commodity prices to new information has been a central question in macroeconomics, focusing on the effect that sticky prices have at the aggregate level. Related theoretical and empirical works have addressed the effects of macroeconomic shocks on commodity storage decisions to account for agents' reactions.

The world aluminium market provides an interesting case study for two different reasons. Firstly, as many industrial commodities, there is no evidence of stockouts and very little empirical support for nonlinear price dynamics in historical data of the aluminium market (Gilbert, 1995).[2] This allows the rational expectations hypothesis (REH) for commodity prices to be consistently imposed and tested in a stockholding equation (Deaton and Laroque, 1992). Secondly, it has been shown that monetary disturbances significantly affect mineral and agricultural prices in the short-run. This phenomenon has been rationalized by Frankel (1986, 1995, 2006) resorting to the "overshooting" theory: a temporary increase in the real interest rate, due, for example, to a decrease in money supply, makes demand for commodities decrease and, consequently, real commodity prices fall until agents will consider them "undervalued"

[2] Non-linearities from stockouts are evident in many agricultural price series and have serious consequences on the tractability of theoretical models and their ability to provide testable predictions (see Deaton and Laroque, 1992, 1996). A complimentary study by Chambers and Bailey (1996) shows how the introduction of time-dependent and periodic disturbances in models of agricultural price determination can account for a wide range of empirical fluctuations.

and formulate expectations of future appreciation. The general price level adjusts in the long-run to the monetary shock and, as a result, the real interest rate and commodity prices eventually return to their initial level.

Basically, the overshooting phenomenon is due to the larger speed of adjustment of agricultural and mineral prices compared to most other prices. In contrast, in many non-ferrous metals industries, including aluminium, producers and consumers sign annual contracts specifying quantities and grades, therefore prices should not instantaneously adjust.

Thus, in this paper, we specify a theoretical framework based on a Cournot competition for modelling the market behaviour of this industrial commodity (Powell, 1993; Gilbert, 1995)[3]. In line with this model, we pursue the confutation of the overshooting theory in the world aluminium market basing on the peculiar features of its functioning. Under the hypotheses of the model, producers do not revise their production levels once the price is known so that, as contracts approach the delivery date, consumers may be able to do arbitrage. This implies that macroeconomic shocks to aluminium price that occur near the delivery date of a given contract may not be fully passed through into the price of that contract. As a result, also hypothesizing agents' rationality, the expected (or future) price might adjust incompletely and exhibit high persistence.

In summary, we focus our study on the following questions: i) How persistent is the effect of an aluminium price shock on the price itself? ii) What is the dynamic relationship between the aluminium stockholding and price behaviour? iii) How

[3] The view that the aluminium industry may be thought of as exhibiting Cournot competition implies that production will be determined by the level of orders rather than by price (Powell, 1993).

important are macroeconomic disturbances in explaining the aluminium stockholding and price variability?

The rest of the paper is organized as follows. In Section 2 some basic descriptive evidence on the relationship between the aluminium world market and macroeconomic variables is provided using dynamic correlations and graphical analysis. The theoretical insights and the empirical tests are obtained in Section 3 by modifying the Gilbert's (1995) rational expectations model of aluminium market and by embedding it in a Structural VAR (SVAR) framework. In Section 4 we discuss estimations, while Section 5 concludes.

II. Preliminary evidence

A preliminary picture of the empirical relationship linking the aluminium market to macroeconomic factors can be obtained by simply computing cross-correlations and plotting graphs of the relevant time series.

Given the dimension of the US economy and its role as a large aluminium producer, we proxy the relevant variables using US data. The only exception is the world demand, proxied by the OECD countries' industrial production.

The data and variables used in this Section are a subset of those employed in the main econometric exercise. In order to avoid severe monetary fluctuation episodes which took place before 1995, we confine our analysis to the monthly sample data spanning January 1995 to July 2004.[4] The variables of interest are the real world aluminium price, p_t, the aluminium inventory demand, s_t, the US real interest rate, r_t, and the US dollar real exchange rate, exc_t.

[4] Details on the construction of variables and sources of data are provided in Appendix.

It is known that the overshooting model of commodity prices proposed by Frankel (1986) predicts that an increase in the real interest rate induces arbitrageurs to shift out of storable commodities, moving into more attractive bonds. In the short-run this will depress both commodity and manufactured market prices, which in the long-run will eventually revert to their equilibrium level. Since commodity prices are in general much more flexible than manufactured ones in the short-run, they must temporarily fall below their long-run equilibrium level, i.e. "overshoot", in order to have a rational anticipation of future capital gains capable of offsetting the higher real interest rate.

[FIGURE 1 ABOUT HERE]

Figure 1 shows that there is no evidence of a negative correlation between the real interest rate and the aluminium spot price. This result is in line with that found by Frankel (2006). In fact, while he finds a significant negative correlation using an aggregate price index, the same relationship is statistically insignificant when tested on the aluminium market. Though this descriptive picture does not exclude in general the short-run behaviour implied by the overshooting theory, the peculiar features of the aluminium market described above provide a rationale for the absence of the negative relationship holding in many other commodity markets.

Being the US one of the main aluminium net exporting countries, an appreciation of the US real exchange rate can lead to an increase in the dollar denominated aluminium price. Thus, the dollar denominated aluminium price and the US real exchange rate should generally be negatively correlated.

[FIGURE 2 ABOUT HERE]

Figure 2 shows a cross plot of the US real exchange rate and the aluminium price. As expected, the correlation coefficient is large and negative (-0.75).

For storable commodities as aluminium, the demand flow is partly determined by inventory decisions. The extra term depends on the utility deriving directly from holding stocks minus the cost of storage including insurance, spoilage, and the interest rate (Ng and Ruge-Murcia, 1997; Miranda and Rui, 1999). Thus, when costs increase, the commodity inventory demand and, therefore, the spot price, drops. To analyse this relationship, consider the world real price, p_t, and stock demand, s_t.

[FIGURE 3 ABOUT HERE]

Figure 3 provides some support to the view that the aluminium price and stock demand are positively related (the correlation coefficient is 0.72), as extensively found by previous literature (Pyndick, 1994, Susmel and Thompson 1997).

The analysis so far rests on simple statistical associations and cannot be used to derive any conclusion about causality links among variables. To investigate further these issues and to answer the questions posed in the introduction, we propose below a theoretical model and a deeper econometric analysis of the world aluminium market.

III. Theoretical framework

In this Section we develop a modified version of the structural model of the aluminium market proposed by Gilbert (1995). In order to bridge the gulf between academic models of commodity markets and procedures routinely used by metals industry analysts to forecast commodity price dynamics, Gilbert introduces two variables: a “short-term fundamental”, measuring the market balance corrected for the gap between the current and the market-clearing price level, and a “long-term fundamental”, measuring the difference between production and consumption trends. He then uses these variables to build a model such that coefficient restrictions allow testing the implications of the REH.

We take the same stance and focus on how macroeconomic variables affect the aluminium stockholding and price dynamics. The structure of the aluminium industry is specified as a competition of producers on quantity and delivery conditions of annual contracts but not on price. If we assume that production is constrained by capacity, producers do not revise their production levels when the price is set by the competitive market. Thus, production depends on current prices and stock changes are in charge of meeting demand. This leads to the current price at the time of delivery and inventory lining up supply to the demand level:

$$\Delta q_t = \beta_0 - \beta_1 \left(q_{t-1} - c_t + E_{t-1} m_t \right) - \beta_2 s_{t-1} + \beta_3 p_t + u_t \qquad (1)$$

where q_t represents aluminium production, c_t is consumption, E_{t-1} is the lagged expectations operator, m_t are US imports, s_{t-1} is the lagged stockholding level, p_t is the current price level, β_i, with i = 0, 1, 2, 3, are parameters, and u_t denotes a stochastic production shock.

The world aluminium consumption, c_t, is a function of i) the world market demand, proxied by the OECD industrial production index, $ipoecd_t$, ii) the monetary policy, measured by the real interest rate, r_t, and iii) the behaviour of economic agents, based on lagged spot prices, p_{t-1}. Formally:

$$c_t = \alpha_0 + \alpha_1 ipoecd_t + \alpha_2 r_t + \alpha_3 p_{t-1} + v_t \qquad (2)$$

where α_i, with i = 0, 1, 2, 3, are parameters, and v_t is a consumption shock.

The macroeconomic variables $ipoecd_t$ and r_t in equation (2) affect aluminium demand within the period and are not assumed *a priori* to be strictly exogenous. Moreover, as mentioned above, the aluminium market structure makes consumption decisions to be planned in advance and, thus, to be dependent on lagged prices. On the other hand, the consumers might be led to revise their plans if unpredictable economic conditions (or shocks) suggest profitable arbitrage.

The US net imports variations are assumed to be a function of the real exchange rate:

$$\Delta m_t = \delta_0 exc_t + w_t \qquad (3)$$

where δ_0 is a parameter and w_t is a stochastic term.

Finally, the hypothesis that agents behave rationally when taking stockholding decisions leads us to formulate a speculative stock demand equation. We assume that the variability in the inventory accumulation process is only caused by its speculative component. This assumption appears reasonable if we consider that in recent years the new inventory management techniques and the electronic automation of the production process have, on one hand, allowed aluminium users to limit precautionary stocks while, on the other hand, have permitted aluminium producers to carry out unexpected orders at higher speed. Basing on the REH, the stockholding equation is given by:

$$s_t = \eta_0 + \eta_1 \left[E_{t-1} p_t - (1 + r_t) p_{t-1} \right] + f_t \qquad (4)$$

where η_i, with i = 0, 1, are parameters and f_t is a stock demand shock. The expression in square brackets is the incentive to hold an additional unit of stock, where we have assumed that the rate of stock depreciation is null (see Gilbert, 1995).

In order to model the specificity of agents' behaviour in the aluminium market we first derive, as a benchmark, a market clearing price from the relationship between the spot price and the net demand. Then, we include the short-term market fundamental, z_{1t}, proposed by Gilbert (1995) to obtain a more general expression that characterizes a disequilibrium relationship as a consequence of incomplete adjustment of aluminium market price to (macroeconomic) shocks near the delivery time.

We define the available quantity $q_t^a \equiv q_t + m_t = q^a(p_t, \bar{K}_{1t})$ where $\bar{K}_{1t}$ is a vector including the macroeconomic variables affecting aluminium supply, that are fixed at time *t*. Likewise, aluminium consumption can be rewritten as $c_t = c(p_t, K_{2t})$ where K_{2t} is a vector of macroeconomic demand-shifting variables. Thus, the market clearing condition in terms of inventory changes is given by:

$$\Delta s_t = q_t + m_t - c_t = q^a(p_t, \bar{K}_{1t}) - c(p_t, K_{2t}) \tag{5}$$

The inverse of equation (5) gives the market clearing price equation:

$$p_t = p(\Delta s_t, \bar{K}_{1t}, K_{2t}) \tag{6}$$

In order to allow for the disequilibrium between supply and demand specific of the aluminium market, we re-parameterize equation (6) as follows:

$$p_t = \lambda(z_{1t} - s_t) \tag{7}$$

where $\lambda = 1/\beta_3$ and $z_{1t} = q_t - \beta_3(p_t - \bar{p}) + m_t - c_t + (s_{t-1} - \bar{s})$ is the short-term market fundamental, with $\bar{p}$ and $\bar{s}$ being the reference levels of the aluminium price and stock, respectively (see Gilbert, 1995; Pieroni and Ricciarelli, 2005).

III.1. VAR model

The assumption of an expectation-formation mechanism in the aluminium market allows us to embed the theoretical framework set out above in a Structural vector autoregressive (SVAR) model.

From equation (7), by assuming that market equilibrium holds, i.e. $p_t = \overline{p}$, we can write:

$$p_t = p(\Delta s_t, \varphi_t) \tag{8}$$

where φ_t is a cumulative innovation that represents the accumulation of shocks over time deriving from specific features of the aluminium market functioning.

From the stockholding rule (4), which incorporates the REH, we now derive an equation describing the pattern of inventory changes.[5] Deaton and Laroque (2003) propose to model short-run stockholding responses to expected price shifts as a growth rate, implying that $\eta_0 = s_{t-1}$. The rationale for this identifying assumption is that speculators react to the observed price lying above or below the expected value, *i.e.* they modify the stockholding function to regress back to the optimal equilibrium. Thus, equation (4) can be rewritten as:

$$\Delta s_t = \eta_1 \left[E_{t-1}\left(p_t \mid I_{t-1} \right) - \left(1 + r_t\right) p_{t-1} \right] + f_t \, . \tag{9}$$

where I_{t-1} is the information set on which agents condition their expectations and f_t is assumed to be a stationary I(0) random variable.

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[5] Note that the REH holds even if prices are sticky since we assume that agents formulate correct expectations by processing all available information (Taylor, 1995).

Since the current price can be expressed as a linear combination of the market variables, we define $\overline{\Delta s_t} = s_{t-1} - \bar{s}$ to be the inventory changes derived from the market clearing equation in a competitive market. Then, we include the solved expected value[6] in (9) and rearrange to obtain:

$$\begin{aligned}\Delta s_t &= \eta_1\lambda\left[\beta_0 + b\alpha_0\right] - \eta_1\lambda E\left(\overline{\Delta s_t} \mid I_{t-1}\right) + \eta_1 E\left(p_t \mid I_{t-1}\right) \\ &+ \eta_1\lambda\alpha_1 bE\left(ipoecd_t \mid I_{t-1}\right) - \eta_1\lambda\delta_0 bE\left(exc_t \mid I_{t-1}\right) + \eta_1\lambda\alpha_1 bE\left(r_t \mid I_{t-1}\right) + f_t\end{aligned} \quad (10)$$

where $b = \beta_1 - 1$, while the remaining symbols are defined above.

Equation (10) is a convenient way to represent the structural equation for the stock demand and is particularly suitable to describe the rational expectation mechanism. To obtain an empirically tractable model, we replace the expected value of the stock demand in (10) with a distributed lag structure (Almon, 1965). In fact, by selecting the optimal polynomial order through statistical tests, we implicitly assume that agents formulate their forecasts taking account of the statistical significance of finite lagged values. This assures forecast accuracy and proxies the rational behaviour in aluminium market (Pieroni and Ricciarelli, 2005).

Multiplying the structural parameters $(\eta_1, \beta_0, \alpha_0, \alpha_1, \alpha_2, \delta_0, \lambda, b)$ by the expectation-shaping mechanism parameters for price and other control variables, the first equation of the VAR model is specified as:

$$\begin{aligned}\Delta s_t &= C_{10} + C_{11}(L)\Delta s_{t-1} + C_{12}(L)p_{t-1} \\ &+ C_{13}(L)ipoecd_{t-1} + C_{14}(L)exc_{t-1} + C_{15}(L)r_{t-1} + f_t\end{aligned} \quad (11)$$

---

[6]The solved expected value is: $E\left(p_t \mid I_{t-1}\right) = E\left(\frac{1}{\beta_3}q_t + \frac{1}{\beta_3}m_t - \frac{1}{\beta_3}c_t - \frac{1}{\beta_3}\overline{\Delta s_t} \mid I_{t-1}\right)$.

where $C_{1i}(L) = c_{10}^{(i)} + c_{11}^{(i)} L + c_{12}^{(i)} L^2 + \ldots + c_{1P}^{(i)} L^P$, L is the lag operator, and $\Delta s_{t-1} = \overline{\Delta s}_{t-1} + \iota_t$, with ι_t being a serially uncorrelated, normally distributed shock, uncorrelated with f_t.

The second equation of the VAR model refers to the aluminium price and is derived from equation (8) by substituting out the expression for the inventory changes (11) and assuming a linear relationship:

$$\begin{aligned} p_t &= C_{20} + C_{21}(L)\Delta s_{t-1} + C_{22}(L) p_{t-1} \\ &+ C_{23}(L) ipoecd_{t-1} + C_{24}(L) exc_{t-1} + C_{25}(L) r_{t-1} + \xi_t \end{aligned} \tag{12}$$

where $C_{2i}(L) = c_{20}^{(i)} + c_{21}^{(i)} L + c_{22}^{(i)} L^2 + \ldots + c_{2P}^{(i)} L^P$, and ξ_t is a mixture of innovations to price, φ_t, and stock changes, f_t.

The coefficients of the matrices C in (11) and (12) are obtained by mixing the model structural parameters $(\eta_1, \beta_0, \alpha_0, \alpha_1, \alpha_2, \delta_0, \lambda, b)$, with the parameters of the polynomial structure in the lag operator that define the expectation-shaping mechanism (see Pieroni and Ricciarelli, 2005, for details). It is worth noting that the coefficients obtained from the VAR estimation are not the structural parameters $(\eta_1, \beta_0, \alpha_0, \alpha_1, \alpha_2, \delta_0, \lambda, b)$ of the theoretical model, but rather a mixture of them with the parameters of the expectations lag structure. Nevertheless, the theoretical model provides the necessary rationalization of the influence exerted by macroeconomic variables on the aluminium market.

As anticipated above, we assume that the macroeconomic factors ($ipoecd_t$, exc_t, r_t,) are endogenously determined and governed by a non-stationary autoregressive stochastic process, with independent, serially uncorrelated, and normally distributed disturbances. Moreover, since equation (12) is derived from the expression (8), the aluminium price must be assumed stationary, with serially uncorrelated and normally distributed disturbance terms.

A general framework that takes into account the model suggestions defines a $k \times 1$ vector Y_t that includes both the aluminium market variables and the macroeconomic indicators. The VAR system is, thus, given by:

$$Y_t = \mu + \sum_{i=1}^{p} \Gamma_i Y_{t-i} + e_t \qquad (13)$$

where $Y_t = (\Delta s_t, p_t, \Delta ipoecd_t, \Delta exc_t, \Delta r_t)'$, μ is a $k \times 1$ vector of constants, Γ_i, for $i = 1,..., p$, are matrices of parameters, and e_t is a k-dimensional vector of observed residuals. Since the theory is silent on if and how the aluminium market variables can affect the macroeconomic ones, apart from the link between the aluminium price and the real exchange rate discussed briefly above, we recover these relationships empirically.

III.2. Identification

In this Subsection we solve the identification problem arising from the system (13). In order to achieve this goal, we discuss a set of assumptions that allow us to recover the structural innovations underlying the error terms. Pre-multiplying the dynamic system (13) by the matrix *A*, we obtain:

$$AY_t = A\mu + A\sum_{i=1}^{p} \Gamma_i Y_{t-i} + Ae_t \qquad (14)$$

It is possible to derive the structural form of the system (14) by considering two $k \times k$ invertible matrices, *A* and *B*, such that:

$$Ae_t = B\varsigma_t \qquad (15)$$

where ς_t is a *k*-dimensional vector of unobserved structural innovations, assumed to be serially uncorrelated and normally distributed with $E(\varsigma_t) = 0$ and $E(\varsigma_t \varsigma_t^{'}) = I$.

The *AB*-SVAR system (14) - (15) models explicitly the instantaneous links among the endogenous variables (matrix *A*) and the correlations among the orthogonal shocks in the structural equations (matrix *B*). Identification is achieved by imposing suitable restrictions on *A* and *B*; when the number of free elements in the specification is smaller than that required obtaining exact identification, the over-identifying restrictions can be tested. The vector of orthonormal structural innovations $\varsigma_t = (\varsigma_{st}, \varsigma_{pt}, \varsigma_{ipoecdt}, \varsigma_{exct}, \varsigma_{rt})$ consists of two groups: the first group relates to the world aluminium market indicators and includes the storage function shock, ς_{st}, along with the aluminium price shock, ς_{pt}, while the second group consists of the shocks to the industrial production - as a proxy for world demand shifts - $\varsigma_{ipoecdt}$, the real exchange rate, ς_{exct}, and the real interest rate, ς_{rt}. We impose a contemporaneous correlation pattern among macroeconomic and aluminium market shocks, whereas the matrix A, specifying the instantaneous relations among endogenous variables, is set equal to an identity matrix, $A = I_k$.[7] Formally:

$$e_{st} = b_{11}\varsigma_{st} + b_{13}\varsigma_{ipoecdt} + b_{14}\varsigma_{exct} + b_{15}\varsigma_{rt} \quad (16)$$

$$e_{pt} = b_{21}\varsigma_{st} + b_{22}\varsigma_{pt} + b_{23}\varsigma_{ipoecdt} + b_{24}\varsigma_{exct} + b_{25}\varsigma_{rt} \quad (17)$$

$$e_{ipoecdt} = b_{33}\varsigma_{ipoecdt} \quad (18)$$

$$e_{exct} = b_{43}\varsigma_{ipoecdt} + b_{44}\varsigma_{exct} \quad (19)$$

$$e_{rt} = b_{53}\varsigma_{ipoecdt} + b_{54}\varsigma_{exct} + b_{55}\varsigma_{rt} \quad (20)$$

[7] Note that the restrictions of the upper left diagonal block of the matrix *A* derive from equations (11) and (12).

It is possible to single out two sets of restrictions corresponding to the two groups of shocks, one for the aluminium market variables (equations (16) and (17)) and the other for the macroeconomic environment (equations (18) - (20)).

The first set derives directly from the theoretical model given by equations (11) and (12). Equation (16) incorporates the assumption that stockholding decisions respond to shocks to the other endogenous variables within the period, except for the aluminium price; this is a result of the peculiar feature of the aluminium market discussed earlier: the high elasticity of production and storage decisions to price changes makes the supply keep in line with the price listed at the time of delivery, while consumption depends on lagged prices. By the same argument, the aluminium price shocks are assumed to be correlated to storing decisions in equation (17). Since the theory is silent about the contemporaneous effect of macroeconomic shocks on the aluminium market, we let it be determined empirically and leave the correlation pattern unrestricted.

Equations (18)-(20) are based on the sensible assumption that aluminium market shocks have no contemporaneous effects on the macroeconomic variables. The remaining restrictions are usually assumed in SVAR macroeconomic models. In particular, equation (18) ensures that demand shocks can affect instantaneously all equations and thus represent a driving force for the other macroeconomic indicators. Equation (19) is based on the assumption that exogenous demand shocks affect within the period the volatile component of the real exchange rate, *i.e.* the nominal exchange rate, which is reasonable if we consider that the foreign exchange market is highly responsive to macroeconomic conditions. In general, however, it would be difficult to determine the direction of causality between domestic output and the real exchange rate. Since we do not belittle this difficulty we also estimate our model inverting the causal order between the two variables as a robustness check; we obtain exactly the same results and therefore we feel encouraged to keep the first specification. Finally, equation (20) assumes that the real interest rate can react to the other shocks within the month, a conjecture advanced in many studies of the US monetary policy.[8]

The system (14) is estimated with the maximum likelihood method.[9] The Akaike's information criterion (AIC), final prediction error (FPE) and likelihood ratio test (LR) are used to choose the number of lags of the unrestricted VAR model. Finally, the impulse response functions (IRF) and the forecast error variance decomposition (FEVD) are computed to analyse the impact of structural shocks on the system variables and the proportion of each variable forecast error variance which is explained by the other shocks in the model.

IV. Results

IV.1. Statistical properties of the series

In order to specify correctly the VAR model, as a first step we implement single-equation based tests to ascertain the variables' order of integration. To obtain robust

[8] Our identification strategy departs from the one commonly used in the empirical literature on the real exchange rates. Following Clarida and Gali (1994) most studies identify the structural shocks of VAR models of the real exchange rate, interest rates, and output through long-run restrictions *a là* Blanchard and Quah (1989). Since in this study, however, we are interested in the short-run relationship between aluminium market and macroeconomic variables, it would be difficult to imagine a consistent set of long-run restrictions on these interactions.

[9] The likelihood function is derived by Amisano and Giannini (1997).

results we perform two unit root tests: the augmented Dickey-Fuller (1979) (ADF) and the Phillips-Perron (1988) (PP) tests.[10]

[TABLE 1 ABOUT HERE]

The results, reported in Table 1, do not reject the presence of a unit root in all variables, except for the world real price of aluminium. Aluminium stocks and macroeconomic variables are integrated of order one, thus confirming our hypotheses.

These findings allow us to estimate an unrestricted VAR(p) system, after checking that all roots are in modulus less than one and lie inside the unit circle. Moreover, we select the lag order using several criteria and we perform lag exclusion tests. Since no root of the characteristic AR polynomial lies outside the unit circle the estimated VAR system satisfies the stationarity conditions. Nevertheless, Table 2 shows that the first eigenvalue is high in modulus implying persistence in the data generating process of one variable.

[TABLE 2 ABOUT HERE]

[10] These tests adopt different methods to check for higher order serial correlation in the innovations. To select the appropriate number of lagged first difference *k*, we use the recursive procedure proposed by Ng and Perron (1995) in the ADF test, while in the PP test the Newey-West consistent estimate correction is implemented at zero frequency (with a truncation at lag 2). For both ADF and PP tests, preliminary regressions have been tried with only an intercept, with intercept and a linear time trend and with none of them. In most of the regressions the time trend is insignificant, while the intercept is highly statistically significant.

The choice of a lag order 2 is supported by either AIC, FPE and LR criteria, as reported in Table 3.

[TABLE 3 ABOUT HERE]

Although the second lag is not significant for all equations, we reject the null hypothesis of exclusion of two lags [χ^2_{25} = 48.25 (p-value = 0.0035)] for the whole model, while we cannot reject it for three lags [χ^2_{25} = 29.25 (p-value = 0.2537)]. The tests on estimated residuals estimations (unreported) exclude overall serial correlation, heteroscedasticity, and normality problems, confirming the validity of the specified model.

IV.2. SVAR estimation

Since our primary interest is in the structural dynamic relationship between the variables, rather that reporting the estimates of the unrestricted VAR parameters, we discuss only some key results.

[TABLE 4 ABOUT HERE]

Firstly, Table 4 shows the Granger's block causality test for the stockholdings and price equations. The values of the Wald test statistics are $\chi^2_8 = 11.15$ (p-value 0.19) and $\chi^2_8 = 5.22$ (p-value 0.73) for Δs_t and p_t respectively, which lead us to conclude that the other factors have an insignificant impact on the aluminium world market key variables, although there is weak evidence of Granger-causality running from the aluminium price to stocks (p-value = 0.08). Secondly, the estimation of the stock equation in the unrestricted VAR shows that the coefficient of the aluminium price at one lag is positive and significant at 5%. This is in line with what expected from speculators' tendency to accumulate inventories in response to positive expected price changes (Miranda and Rui, 1999) and supports the Granger non-causality test for aluminium price in the stock equation. It is worth remembering, however, that the Granger non-causality test results could be underestimated due to the likely dynamic and contemporaneous interactions between the variables of the aluminium market and the macroeconomic determinants.

The just-identifying restrictions described by equations (16) – (20) are imposed in the unrestricted VAR(2) to obtain a benchmark SVAR. The resulting structural parameters estimates are given by the first column of Table 5.

[TABLE 5 ABOUT HERE]

Several findings stand out. Firstly, the contemporaneous effect of stock changes on aluminium price is statistically insignificant [$b_{21} = 0.0027$ (p-value = 0.415)], though its inclusion in the empirical specification is consistent with the theoretical framework summarized by equations (11) and (12). Secondly, as highlighted by previous literature, there is a strong impact of the real exchange rate on the world aluminium price. In particular the coefficient b_{24} has a negative sign and is significant at the conventional level [$b_{24} = -0.0070$ (p-value = 0.0338)]. Thirdly, the negative value of b_{25} supports the hypothesis of a negative relationship between interest rates and commodity prices, though the high p-value confirms that this relation is statistically insignificant for aluminium, consistently with Frankel's (2005) results. Fourthly, it is important to notice that stockholdings and macroeconomic shocks are uncorrelated within the period, likely due to the capacity constraints of producers that characterize this metal industry.

In order to better understand the transmission channels of macroeconomic shocks to the world aluminium market, a parsimonious specification of the SVAR model is obtained by imposing and testing further restrictions basing on the *p*-values of the B matrix.

The eight over-identifying restrictions are not rejected, as the LR test reported in the bottom part of Table 5 shows with a $\chi_8^2 = 9.27$ and a *p*-value = 0.32. Therefore, we base the following analysis on the parsimonious SVAR model.

The parameters estimations are reported in the second column of Table 5 and show the expected signs. Note that in the parsimonious specification the structural demand shock coefficient in the real interest rate equation is, as predicted by theory, positive and statistically significant.

In order to analyse the impact of structural shocks on the variables of the SVAR model we report, in Figure 4, the impulse response functions together with Hall bootstrap confidence intervals based on 10.000 bootstrap replications (Lütkepohl and Krätzig, 2004).

[FIGURE 4 ABOUT HERE]

The order of the shocks corresponds to that of the variables in the system (14), i.e. $\varsigma_{st}, \varsigma_{pt}, \varsigma_{ipoecdt}, \varsigma_{exct}, \varsigma_{rt}$. Since some of the effects are marginally significant, we concentrate our comments on key findings. The peculiar behaviour of the aluminium market is confirmed by the dynamics of stocks following an interest rate shock: the response is insignificantly different from zero until the fourth month when it is significantly positive, before becoming statistically null again, thus implying that investors anticipate the persistent effect on prices and thus increase temporarily their stock to take advantage of it. This argument is supported by the response of aluminium inventories to a positive shock to prices: expectations of a slow return to equilibrium of prices will induce speculators to increase their holdings temporarily. In response to a one standard deviation shock to itself, the world aluminium price increases considerably and the effect takes about 48 months to die out. As expected from the functioning of the aluminium market, we find smooth responses of prices and long horizons of convergence. Given the estimation results of matrix B, the impact effect of the real exchange rate shock on aluminium price is significant and negative, thus confirming the preliminary evidence provided by the contemporaneous correlation discussed in Section 2. The supplementary information provided by the IRF analysis is that this effect is long lasting, although it is insignificant from the second month on. It is worth noting, moreover, that the effect of an exchange rate shock on the aluminium price is larger than on any other variable in the model.[11] The positive response of the aluminium price to a real interest rate shock, though slightly significant after two months, confirms the exceptional features of the aluminium market functioning with respect to other commodity markets, and thus provides a rationale for the results of Frankel's studies on the subject: in the aluminium market prices are set in advance of quantities, with the latter adjusted accordingly; being sluggish, the aluminium price does not reveal any decreasing response and any overshooting dynamics following a shock to interest rates.

[11] This result should be taken with caution since it is not clear how an exogenous shock to the real exchange rate in a large economy such as the US is to be understood.

Rather, the aluminium price tends to remain persistently higher than its long-run (equilibrium) level suggesting that its adjustment process is even slower than that of the general level of prices. The negligible response of the price to stockholding shocks reinforce the hypothesis that the contracting mechanism in the aluminium market makes the quantities adjust to predetermined prices.

Regarding the relationship among macroeconomic variables, the evidence confirms what emerges from previous literature. An unexpected shock to output causes an increase in US interest rates, though the response is restricted to be zero on impact in the parsimonious SVAR. The subsequent reaction is barely different from zero probably due to the fact that US output is only a part, though relevant, of OECD industrial production. A shock to output has a negligible influence on the real exchange rate as a consequence of the composite measure of industrial production that compensates responses to single components. The US interest rate increases sharply and significantly in response to an output shock, but this effect vanishes after three months.

In order to understand the importance of macroeconomic factors in explaining the aluminium market price and stock variability, we now turn to the analysis of the Forecast Error Variance Decomposition (FEVD), basing again on the parsimonious structural identification of contemporaneous shocks developed earlier. The aluminium stock variability is mostly explained by itself, but price innovations come next, and macroeconomic factors are also important, especially world demand. Variations in aluminium price are largely explained by innovations in price itself at all horizons. The proportion of the price forecast error variance due to stockholdings is insignificant, while an important contribution is given by macroeconomic variables, and specifically by the real exchange rate, the real interest rate and output, respectively. Overall, macroeconomic shocks explain more than 10% of aluminium price forecast error variance from the fifth month onwards, while they explain almost 7% of stockholdings variability at all horizons. On the other hand, aluminium stockholdings explain a significant proportion of world demand and US real interest rate variability. As for the FEVD of macroeconomic variables, it is noticeable that almost 10% of the interest rate variability is accounted for by output shocks.

V. Concluding Remarks

Traditionally, studies on metal and agricultural commodity markets have focused on the microeconomic behaviour of agents. Analyses regarding the relationship between commodity markets and macroeconomic factors have attracted less attention, though the recent generalized increase of commodity prices have brought back a renewed interest in them.

The purpose of this paper is to test the interaction between the aluminium market and some macroconomic fundamentals through a structural model that allows for disequilibrium on quantities as a specific features of contracts in the market. Our results can be summarized as follows. Firstly, while the real exchange rate has a significant impact on the aluminium price, the effect of a shock to the real interest rate is almost null. We confirm the results provided by Frankel (2006) showing that the "overshooting" theory only holds for agricultural and mineral commodities, while it is much weaker for non-ferrous metals. We interpret this result resorting to the peculiar features of the aluminium market functioning in which the producers' competition based on the contracts quantity conditions makes prices sluggish over time. This is confirmed by the response of the aluminium price to its own shock: it is large and significant over a long period, dying out after almost 4 years. Further support to this interpretation is offered by the FEVD showing that the aluminium price variability is almost entirely due to itself, while the contribution of stockholdings is insignificant at all horizons. Secondly, macroeconomic shocks explain on the whole more than 10% of aluminium price forecast error variance from the fifth month onwards, while they explain almost 7% of stockholdings variability at all horizons, thus confirming the importance of macroeconomic variables for understanding the aluminium market behaviour.

To sum up, the analysis conducted here enables us to conclude that a modelling strategy allowing explicitly for the relationship between macroeconomic variables and the rational microeconomic behaviour of agents may improve largely our understanding of commodity markets.

Data Appendix

Data are monthly and span the period from January 1995 to July 2004.

p_t: Real world aluminium price computed as the logarithm of the London Metal Exchange quotation of aluminium deflated by the US producer price index (PPI). Source: London Metal Exchange (aluminium price) and OECD Statistical Compendium CD-ROM (PPI).

s_t: The new definition of unwrought aluminium is used starting from the end of 1999. The International Primary Aluminium Institute (IPAI) produces the conversion rates for time series of aluminium inventory before this year. Source: IPAI.

$ipoecd_t$: OECD countries' industrial production index. Source: OECD Statistical Compendium CD-ROM.

exc_t : US real exchange rate constructed as the ratio of the effective nominal exchange rate and the consumer price index (CPI). The effective nominal exchange rate is given by a weighted average of the bilateral exchange rate of the US dollar with the main trading partners' currencies, with weights given by exports and imports shares. Source: Federal Reserve Bulletin.

r_t : Weighted Europe (12) and US real interest rate. Source: OECD Statistical Compendium CD-ROM.

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Table 1 – Unit root tests

Augmented Dickey-Fuller Test – $ADF(p)$

Levels					*First differences*				
s_t	p_t	$ipoecd_t$	exc_t	r_t	s_t	p_t	$ipoecd_t$	exc_t	r_t
-2.100 (0)	-3.403 (0)	-0.953 (1)	-1.634 (1)	-1.473 (2)	-9.580 (1)	-9.716 (1)	-15.809 (0)	-7.371 (0)	-9.257 (1)
[0.245]	[0.013]	[0.768]	[0.462]	[0.833]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Phillips-Perron Test – $PP(\ell)$

Levels					*First differences*				
s_t	p_t	$ipoecd_t$	exc_t	r_t	s_t	p_t	$ipoecd_t$	exc_t	r_t
-2.045 (7)	-3.393 (2)	-0.998 (1)	-1.379 (5)	-2.017 (2)	-11.293 (8)	-9.679 (5)	-15.254 (5)	-7.154 (14)	-8.387 (2)
[0.268]	[0.013]	[0.752]	[0.590]	[0.586]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Notes: figures in parentheses denote the number of lagged dependent variables in the ADF test equation and the Newey-West bandwidth for the PP test, respectively. Figures in squared brackets are MacKinnon (1996) one-tailed p-values.

Table 2 – Roots of the Characteristic Polynomial

Root	Modulus
0.917008	0.917008
0.066911 - 0.548523i	0.552589
0.066911 + 0.548523i	0.552589
-0.288445 - 0.382570i	0.479124
-0.288445 + 0.382570i	0.479124
-0.028716 - 0.475948i	0.476814
-0.028716 + 0.475948i	0.476814
0.211717 - 0.329640i	0.391774
0.211717 + 0.329640i	0.391774
0.128337	0.128337

Notes: No root lies outside the unit circle.

Table 3 – VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC
0	972.560	NA	8.11e-15	-18.25585
1	1102.085	244.3873	1.13e-15	-20.22803
2	1127.404	45.38168*	1.13e-15*	-20.23403*
3	1144.636	29.26341	1.31e-15	-20.08748
4	1161.532	27.09618	1.55e-15	-19.93456
5	1172.113	15.97168	2.09e-15	-19.66251
6	1196.589	34.63597	2.19e-15	-19.65262
7	1214.066	23.08311	2.66e-15	-19.51068
8	1231.616	21.52340	3.29e-15	-19.37012

Notes: * indicates the lag order selected by the criterion.

LR: sequential modified LR test statistic (each test at 5% level)..
FPE: Final prediction error.
AIC: Akaike information criterion.

Table 4 – VAR Granger Causality/Block Exogeneity Wald Tests

Dependent variable: Δs_t

Excluded	Chi-sq	df	Prob.
p_t	5.051920	2	0.0800
$\Delta ipoecd_t$	3.768844	2	0.1519
Δexc_t	0.674737	2	0.7136
Δr_t	0.714741	2	0.6995
All	11.14504	8	0.1936

Dependent variable: p_t

Excluded	Chi-sq	df	Prob.
Δs_t	0.008919	2	0.9956
$\Delta ipoecd_t$	1.208039	2	0.5466
Δexc_t	0.119467	2	0.9420
Δr_t	2.740182	2	0.2541
All	5.223023	8	0.7335

Table 5 – Estimated SVAR parameters of the benchmark and parsimonious models

Structural Parameters	Benchmark Model	Parsimonious Model
b_{11}	0.0300 [0.000]	0.0307 [0.000]
b_{21}	0.0027 [0.415]	-
b_{22}	0.0344 [0.000]	0.0347 [0.000]
b_{13}	-0.0035 [0.228]	-
b_{23}	-0.0022 [0519]	-
b_{33}	0.0084 [0.000]	0.0084 [0.000]
b_{43}	0.0017 [0.103]	-
b_{53}	0.0793 [0.004]	0.0793 [0.0043]
b_{14}	-0.0034 [0.238]	-
b_{24}	-0.0070 [0.0338]	-0.0073 [0.0282]
b_{44}	0.0107 [0.000]	0.0108 [0.0000]
b_{54}	-0.0135 [0.619]	-
b_{15}	-0.0038 [0.181]	-
b_{25}	-0.0032 [0.326]	-
b_{55}	0.288 [0.000]	0.288 [0.000]
Over-identifying restrictions	-	χ^2_8 =9.27 [0.320]

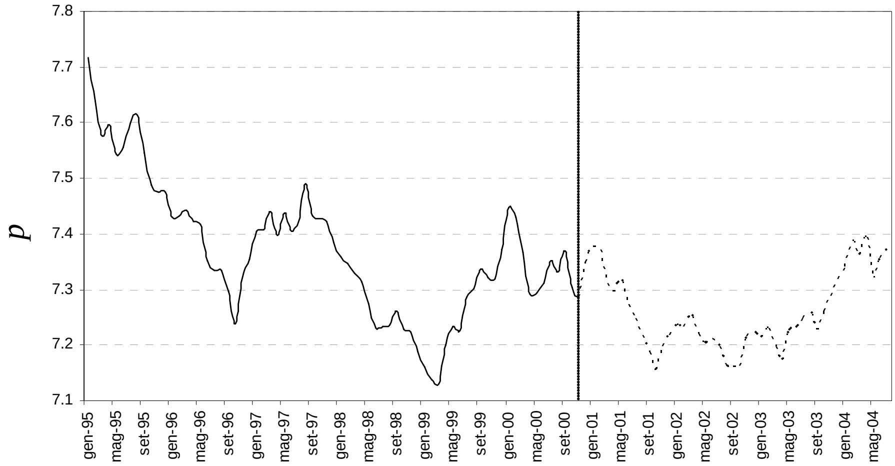
Notes: *p*-values are reported in squared brackets

Table 6 – Forecast error variance decompositions (parsimonious SVAR)

Period	SE	Shocks to				
		Δs	*p*	*Δipoecd*	*Δexc*	*Δr*
				Δs		
1	0.03	100.00	0.00	0.00	0.00	0.00
4	0.03	89.47	4.36	2.96	1.48	1.73
8	0.03	89.13	4.35	3.01	1.48	2.04
12	0.03	89.12	4.35	3.01	1.48	2.04
				p		
1	0.04	0.00	95.79	0.00	4.21	0.00
4	0.07	0.05	90.03	1.91	4.95	3.06
8	0.09	0.06	89.32	2.29	4.89	3.44
12	0.09	0.07	89.11	2.39	4.87	3.57
				Δipoecd		
1	0.01	0.00	0.00	100.00	0.00	0.00
4	0.01	2.02	1.20	95.00	0.21	1.57
8	0.01	2.12	1.31	94.76	0.22	1.59
12	0.01	2.12	1.35	94.72	0.22	1.59
				Δexc		
1	0.01	0.00	0.00	0.00	100.00	0.00
4	0.01	0.19	6.12	0.59	91.80	1.30
8	0.01	0.21	6.61	0.66	90.96	1.57
12	0.01	0.21	6.90	0.67	90.64	1.58
				Δr		
1	0.30	0.00	0.00	7.04	0.00	92.96
4	0.32	1.27	0.36	9.46	0.51	88.41
8	0.32	1.30	0.49	9.50	0.53	88.18
12	0.32	1.30	0.56	9.50	0.53	88.12

Figure 1 – Dynamic pattern of the world aluminium price and real interest rate

a) World aluminium price



b) Real interest rate

Figure 2 – US real exchange rate and aluminium price

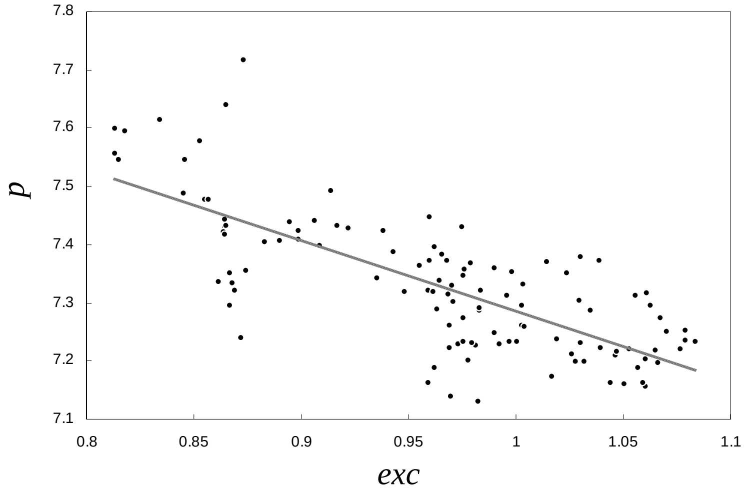


Figure 3 – Aluminium stock demand and price

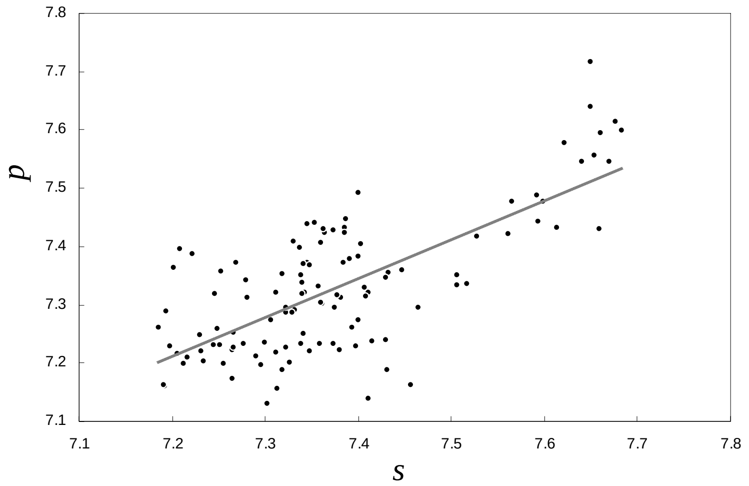
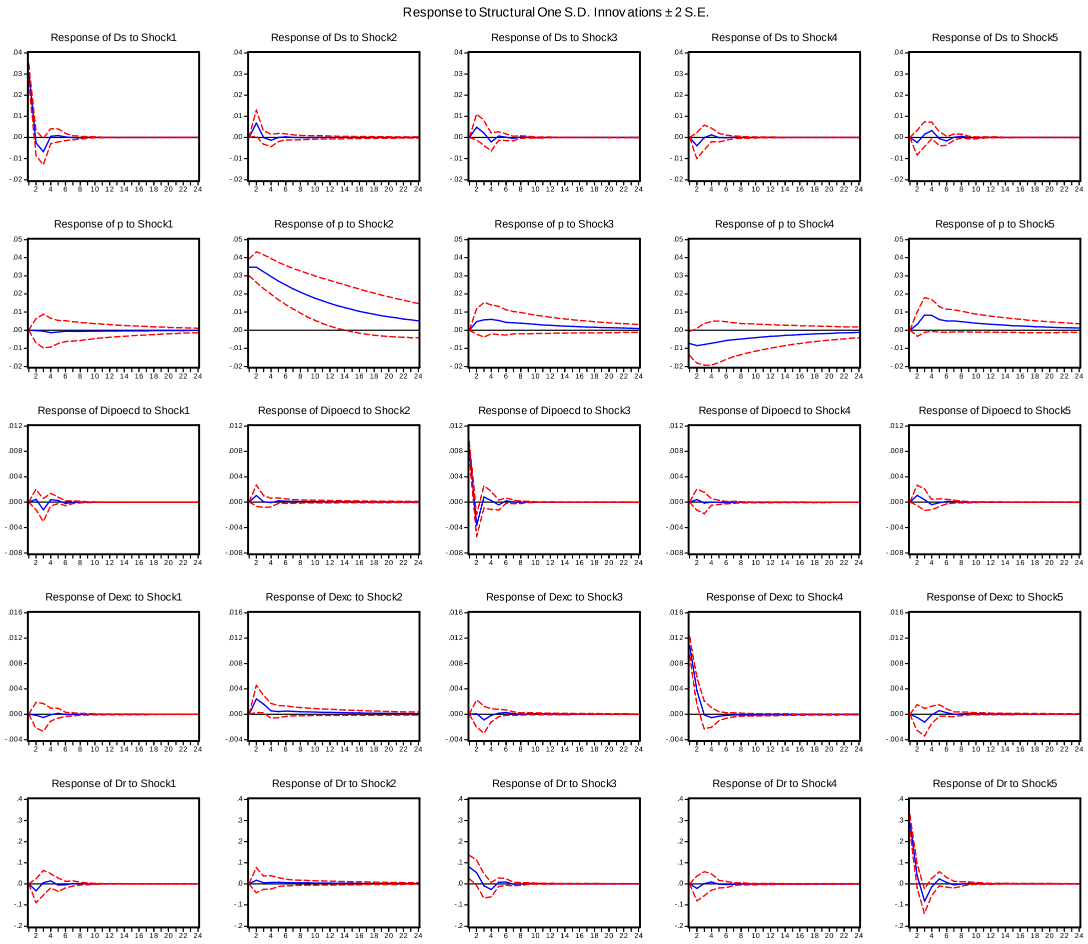


Figure 4 – Impulse Response Functions (parsimonius SVAR)



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