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Prices and Production Cost in Aluminium Smelting in the Short and the Long run

Abstract

The main objective of this work is to reflect the structural changes that have characterized the aluminium industry over the last few decades. I order to capture the changes in competition I have estimated cost and related it to output prices by illustrating the effect of the prevalent industry risk sharing agreements. I argue that, contrary to what the microeconomic paradigm envisages, in the short run prices mainly determine costs as the consequence of a an exchange pricing system involving contractual risk-sharing arrangements. Costs determine prices only in the long run through investment in new smelting capacity. Previous studies of the aluminium industry had often used unreliable measures of weighted average variable cost. The main contribution of this work lies on the estimation of cost applying the flexible translog framework to a unique set of proprietary data.

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1. Introduction:

The standard microeconomic paradigm envisages a direct link between cost and prices which firms set on a variable mar-up basis in relation to the position and slope of the product demand curve. This paradigm applies most directly to manufacturing industry. It cannot be applied without modification to raw materials producing industries in which prices are set on competitive exchanges. In such markets, firms have no direct control over prices and the relationship between production cost and prices must therefore be indirect. In this paper, I attempt to characterize the cost-price relationships in the aluminium industry.

Historically, the aluminium industry was mainly dominated by a group of six large multinational companies, which set producer prices on cost class basis. However concentration diminished significantly[2] during the 1970's and 1980's, and with the start on aluminium futures trading on the London Metal Exchange (LME) in 1978 the major producer lost their ability to directly control prices. By the mid 1980's aluminium was effectively sold world-wide on the basis of LME quotations. Since then there has been significant change on the determination of price cost margins.

It is widely hold that mineral companies have not been highly profitable over the last two decades. One explanation to this is that long term price trends have been unfavourable due to the effects of globalization on mining companies. Firms can no longer control prices and have reacted to the increased international competition by focusing on cost reduction and increased efficiency through economies of scale, mergers, acquisitions and technological improvements to facilities. Three major mergers and several smaller ones were completed in the ongoing consolidation of aluminium smelting and manufacturing capacity. In the year 2000 Alcoa Inc. and Reynolds Metals Company Limited completed their merger after receiving approval from regulatory activities. Alcoa remained the largest producer of primary aluminium. Over the same year, Alcan Aluminium completed its merger with Alusuisse to become Alcan Inc. the largest packaging company in the world. Additionally Russky Aluminii, or Russian Aluminium, was formed through an amalgamation of Sibersky Aluminium´s assets with

[2] For figures and discussion in concentration and market power, see chapter 1 p.11-15.

the aluminium interest of Sibneft Oil. Related factors such as the large increase in exports from the Russia and the other ex-Soviet republics in recent years has also contributed to the downward pressure in profits, as well as the increase in productivity due to the entrance of new more efficient firms into the market.

The major cost components in aluminium production are the cost of the raw material and the cost of electricity required to release aluminium metal from the alumina feed. Aluminium smelters frequently draw their power from dedicated (often hydro) electricity generation plants which do not have alternative buyers for their power. For this reason smelters, electricity generators and alumina refineries are often linked by risk sharing contracts, with the consequence that power input prices vary with the aluminium price. In aluminium, therefore the direct link is mainly from price to costs and not from costs to price. In order to see how costs influence prices we need to consider investment in new smelting capacity, which will depend on production costs through the profitability of both current production and new investment.

The changes outlined above that have taken place within the aluminium production and price setting structure motivate the development of the present study. The main purpose of this paper is to estimate the cost structure of aluminium smelting and to look at the relationship between costs and output prices taking into account the prevalence of industry risk sharing agreements.

The model is developed in three stages:

1. Estimation of the translog cost function for aluminium smelting. The use of this technique to estimate cost is related to the work of Lindquiest (1998), who applied the translog function to panel data for six Norwegian aluminium smelting plants. Earlier studies of the aluminium industry, such as that of Rosebaum (1987), Froem and Gewe (1987) and Donowitz et al. (1987) had to assume fixed input coefficients and constant returns to scale. As a consequence the standard way to calculate margins, involved a measure of average variable cost, often not reliable due to the lack of accuracy of production cost reports. It turns out that if the fixed input demand and constant returns to scale assumptions are not valid, the standard way of calculating cost is not correct and leads to an incorrect inference about cost and its relationship with price over time. This motivates the application of the translog framework to a proprietary set of industry level data.

2. Once the cost structure is estimated, I relate this to industry prices. I do this by distinguishing between the short and the long run. To model the short run dynamics, I set up a series of relationships showing the impact of aluminium price on power and alumina input prices. In order to relate cost and prices in the long run I set up an equation relating investment in new smelter capacity to profitability and a measure of Tobin's Q for the aluminium sector.
3. The model is closed up with the demand and supply equations reflecting the price setting behaviour within aluminium smelting. The former consists of a crude relationship linking the change in the aluminium price to the balance between aluminium consumption and capacity. In the latter production is restricted to be autoregressive and dependent on production capacity and lagged prices.

This model allows me to determine the relationship between cost and prices, and trace out the effects of shocks to either costs or to the aluminium price on the complete set of price, cost, and production variables. It is made possible through the availability of a proprietary set of aluminium production cost capacity data provided by a consulting company.

The remainder of this chapter falls into seven sections. Section 2 provides a full description of the data. In section 3 I set up the translog cost function to describe the aluminium cost structure. In section 4 I describe the short and price-cost relationships. In section 5 I set up the long run relationship between cost and prices. In section 4.6 I close the model by setting up the demand and supply schedules for aluminium smelting and linking production capacity to output prices.. I conclude in section 7.

2. Data description

I have a complete set of aluminium annual cost data covering the period 1982-1998. This includes data for total weighted average variable cost, power cost, power use, alumina price, alumina cost and capacity. These data were provided by the consulting firm Anthony Birds Associates. Annual data on aluminium consumption and production were obtained from the World Bulletin of Metal Statistics (WBMS)

To estimate the aluminium investment structure I have used

- Aluminium share price yearly data for the major aluminium producers: Alcan (Canada), Alcoa (USA), and Reynolds (USA) for the period 1975 to 2000 (Datastream)
- US capital equipment US yearly data for the period 1970-1999 (IMF, *International Financial Statistics*, September 2000)
- Annual average data on the nominal interest rates: US 3 year government bond rate (IMF, *International Financial Statistics*, September 2000)

3. Model specification for the aluminium production process: the translog function

I set up a market model determining prices where each firm is a price taker and minimizes production costs for given prices. I justify this assumption by recognizing that from the mid-eighties, individual producers lost their ability to control prices as the consequence of the LME price becoming the industry market price standard. Over the same period, industry concentration has dropped significantly (see I.Figuerola-Ferretti (2002) p11-15) to the extent that individual firms can now be described as 'price takers'. The firm level model consists of a translog cost function and two price equations reflecting the risk sharing contracts, which determine the short-run input-output price relationships. I link this production side framework to the market environment defined by supply and demand equations, via an investment equation relating investment (defined as the change in capacity) to profits, and a measure of Tobin's q. This allows me to set up a long run relationship between cost and prices, by establishing that lower cost (and thus higher profits) lead to higher investment. I close the model with a relationship linking the metal price to the balance between capacity and consumption, and tree additional consumption, price and output equations representing the demand and supply framework within aluminium smelting. I model consumption as a function of industrial production and lagged aluminium prices, and output as a function of capacity and lagged aluminium prices. The complete set of equations allow model simulation and impulse response analysis (see section 4.7) allowing me to trace out the effects of shocks to each of the variables in the system.

3.1 Theoretical considerations

In the empirical estimation of the aluminium cost structure I have used a non-homothetic transcendental logarithmic (translog) cost function[3]. This is a second order approximation to an arbitrary production function. Unlike the Cobb Douglas and the CES functions, this cost function does not impose any restrictions on the substitution possibilities among the inputs of production. It also allows scale economies to vary with the level of output and, more importantly, it allows input shares to vary over time. This is of particular importance for the aluminium production process since evidence shows that input demands have not been constant over time. For instance in 1950's it took on average around the world about 21 kWh to produce a single kilogram of aluminium from alumina. In 1997 it took one of the newest smelters just 14kWh. Figures 4.A.1-4.A.6 in appendix 4.A plot alumina and power input share values as well as estimated cross and own elasticities of substitution for the 1982-1998 period. The graphs show that neither input demands nor the substitution elasticities within in aluminium production have been constant through our sample period. For this reason we adopt the translog framework in order to allow input demands, substitution and price elasticities to change over time.

The translog cost function may be written as:

$$\ln C = \alpha_0 + \alpha_y \ln y + \frac{1}{2}\alpha_{yy}(\ln y)^2 + \sum_{i=1}^{n}\alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\gamma_{i,j} \ln p_i \ln p_j + \sum_{i=1}^{n}\gamma_{iy} \ln p_i \ln y \quad (1)$$

where:

C is total variable cost obtained by adding alumina cost and power cost[4]

p_i is the input i price where i= A,E are alumina and power electricity price.

Y is output measured as production in the aluminium industry

In order to be well behaved the cost function must satisfy the following conditions

1) Monotonicity: the cost function should be non negative for every $y \in V(y), p_i > 0$ it and it must be non-decreasing in input prices $c(p_0, y) \le c(p_1, y)$ when $p_0 \le p_1$
2) Concavity: $C(tp_a + (1-t)p_E, y) \ge tC(p_a, y) + (1-t)C(p_{E,}y)$

[3] For a theoretical discussion see Paraskevopopoulos (2000)

[4] The Weighted Average Variable Cost also includes a small residual cost which I do not model. Instead I choose to model the sum of alumina and power costs.

I impose the symmetry and homogeneity of degree one restrictions, which allow the integration of the cost function into the production function:

3) Symmetry

$$\gamma_{AE} = \gamma_{EA}$$
$$\gamma_{EA} = \gamma_{AE} \qquad (2)$$

4) Homogeneity of degree one

$$\alpha_A + \alpha_E = 1$$
$$\gamma_{AA} + \gamma_{AE} = 0$$
$$\gamma_{EE} + \gamma_{EA} = 0 \qquad (3)$$
$$\gamma_{yA} + \gamma_{YE} = 0$$

Applying Shephard's lemma to (1) gives the cost share equation for each variable input noting that the first equation in system (4.3) implies that the cost shares have to meet the restriction

$$\sum_{i=1}^{n} S_i = 1 \qquad (4)$$

I estimate the following system:

$$\ln C = \alpha_0 + \alpha_y \ln y + \frac{1}{2}\alpha_{yy}(\ln y)^2 + \alpha_A \ln p_A + \gamma_{AE} \ln p_A \ln p_E + \frac{1}{2}\gamma_{AA} \ln(p_A)^2 + \gamma_{AY} \ln p_A \ln y$$
$$S_A = \alpha_A + \alpha_{AA} \log(p_A) + \gamma_{AE} \log(p_E) + \gamma_{AY} \log(y) \qquad (5)$$

subject to restrictions (2), (3), and (4). This model allows input demands to depend on exogenous input prices and output and therefore provides a framework in which one can undertake comparative static analysis on the aluminium cost and input demand structure.

3.2. Estimation method

I perform all estimations using Iterated Three Stage Leas Squares (I3SLS) on the sub-system consisting of production and the factor shares. Systems estimation allows consideration of the nonlinearities and cross symmetry conditions. Additional instruments are the one and two period lagged values of aluminium and input price returns, and the one period lagged production and capacity variables. Use of these instruments is justified in terms of the presence of these variables in the reduced forms for input prices and production.

3.3 Estimation results

Table 1: Translog Cost Function Estimates

	Coefficient	Std. Error	t-Statistic	Prob.
α_0	-9.179526	16.43749	-0.558451	0.5819
α_y	2.822613	3.428152	0.823363	0.4188
α_{yy}	-0.251496	0.360059	-0.698484	0.4919
α_A	0.170048	0.407674	0.417117	0.6805
γ_{AE}	0.076790	0.004499	17.06671	0.0000
γ_{AA}	0.194465	0.031258	6.221216	0.0000
γ_{AY}	-0.090672	0.048291	-1.877619	0.0732
α_E	0.340096	0.407674	0.417117	0.6805
γ_{EE}	-0.076790	0.004499	17.06671	0.0000
γ_{EY}	0.090672	0.048291	-1.877619	0.0732
SE of regression	0.004115			
R^2_C	0.999234	DW_c	0.6976	
R^2_A	0.608387	DW_A	1.320706	

The table gives the OLS estimates of the pair of equations defined by (5).

Table 4.1 shows the results from estimating the system. The cost function is well behaved if it satisfies the monotonicity and concavity conditions. The parameters α_A (0.1700) and α_E (0.8300) are the average shares of alumina and power inputs over the sample period, they should be non-negative if the cost function is to satisfy monotonicity. Furthermore, we impose that their sum is equal to one. The estimates are positive but insignificant. In order to test for monotonicity, I look at the fitted shares. The predicted average shares are 57.58% for alumina and 42.43% for power. Fitted weighted average variable cost values are positive at all points and highly correlated with the true values. Fitted alumina and power input share values are also positive at all points over the sample period and highly correlated with the true values (see graphs A.1.1 and A.1.2 and A.1.3 in appendix A) suggesting that the translog cost function is monotonic.

The parameters which correspond to the second order terms of the translog cost function, γ_{AA} (0.1945), γ_{EE} (-0.0768), γ_{AE} (0.0768), γ_{EA} (0.0768), may be seen as constant share elasticities. They are derived from partial differentiation of the factor demands (shares) with respect to input prices. They generate the factor share percentage shifts for the given change in input prices. The estimates are not all correctly signed. For instance the own price parameters γ_{AA}, γ_{EE} should in principle be negative as one expects the demand for alumina and power to decrease as alumina and power prices increase. Contrary to expectations, the estimated coefficient γ_{AA} is positive and significant. This suggests that there may be second order violations, but this may not yet be a problem as the bordered Hessian matrix depends on the factor shares as well as the constant share elasticities. Power is however price responsive as the constant own share elasticity is negative and significant. Its value shows that the total power share will decrease by 0.8% if the power price rises by 10%.

The cross share elasticities[5] γ_{AP}, γ_{EA} may in principle be either positive, negative or zero depending on whether the inputs involved are substitutes (positive), complements (negative) or neutral (zero). The estimated coefficient γ_{AE} is positive and significant indicating that, there is some degree of substitutability between power and alumina. It indicates that the alumina share should rise by 0.8% when power price rises by 10%. Given that we are looking at industry level data this can be interpreted as reflecting the improvements in technology that have led to electricity saving techniques within aluminium smelting (see p. 89) and the subsequent substitution of power for alumina.

Given the share parameter estimates, one can check the second order conditions by calculating the substitution and price elasticities.[6] Concavity requires that the matrix of substitution elasticities is negative semi-definite. As can be seen in Appendix 4.A.2 and 4.A.3, own price and substitution elasticities are negative at all points, and cross substitution and price elasticities are positive at all points, demonstrating that the concavity property is not violated. The mean Allen own price elasticities[7] ε_{AA} (-1.2371) and ε_{EE} (-1.0458) are negative. The mean cross price elasticities ε_{AE} (0.1019) and ε_{EA} (0.1360) are positive indicating that alumina and power are substitutes.[8]

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[5] Note that the symmetry condition restricts these two parameters to be the same.
[6] For substitution elasticities See Paraskevopoulos 2001 (p. 41) .
[7] Note that the interpretation of the price and substitution elasticities is very similar to that offered by the second order parameters (constant share price elasticities). However they differ in their magnitude because the price and substitution elasticities depend on the second order parameters of the cost function as well as on their fitted shares.
[8] This is verified by the eigenvalues of the mean Allen price elasticity matrixes which are both negative (-1.5402, -0.7427) indicating that the matrix is negative semidefinite.

I now discuss the share elasticities concerning changes in output. γ_{AY} (-0.09067) and γ_{EY} (0.09067) indicate by how much alumina/power input share increases given a percentage change in output. γ_{yA} is negative and marginally significant indicating that when output increases demand for alumina decreases[9] and the demand for power electricity increases, as indicated by the sign of the parameter γ_{yp}.[10]. The parameters γ_{iY} could also be viewed as the change in cost flexibility caused by a shift in the price of input I (see Paraskevopoulos 2000 p. 44). The parameters α_y (2.822814) can be viewed as the average cost flexibility[11] over the years. It is positive and greater than one suggesting that the aluminium smelting plants exhibit diseconomies of size. Nevertheless it is not significant. Old aluminium smelting plants may experience diseconomies of size due to plant over investment. The parameter α_{yy} (-0.251496) measures the cost flexibility response to changes in output. It is negative and indicates that when output increases by 1% cost flexibility decreases by 0.25%. However the parameter is not significant.

Since some of our estimated output parameters are insignificant, I have looked for possible parsimonious simplifications. Table 2 shows results of these tests.[12]

TABLE 2: Hypothesis testing

Hypotheses	Number of restrictions	χ^2 value	χ^2 p value
Homotheticity	1	3.5254	0.0604
Homogeneity	2	4.3097	0.1159
CRTS	3	4723.29	0.000
UELST	1	291.272	0.0000
HUELST	2	300.0080	0.0000
Cobb Douglas	4	127.05	0.0000
CRTS	Constant Returns to Scale		
UELST	Unitary Elasticity of Substitution		
HUELAST	Homotheticity and Unitary Elasticity of Substitution		

The table gives the outcomes of the likelihood ratio tests on the restrcitions imposed in the model, estimates of which were reported in Table 4.1.

9 Note that this suggests that alumina is an inferior or regressive good, contrary to what one would expect a priori.

10 Note that not all the output share elasticities should have a negative sign as firms should not be able to increase their output while decreasing the utilization of the inputs. In terms of the cost function properties this would violate monotonicity.

11 Cost flexibility is the elasticity of cost with respect to output (see Paraskevopoulos 2000 p 45).

12 See Paraskevopoulos 2000 p. 45-46 for discussion on restrictions for testing different models.

Whereas it can be argued that there is weak evidence supporting homotheticity, our model strongly rejects any further simplification.

4. The short run price cost relationships:

In this section I characterize short run relationship between aluminium input cost and output prices. Because the price of alumina and power electricity are linked to the aluminium price via risk sharing contracts we argue that in the short run output prices determine input prices.

4.1. The effect of aluminium prices on alumina prices

A plot of annual observations of the logs of alumina and aluminium prices for the 1982-1998 period[13] suggests that lagged aluminium prices are positively related to current alumina prices. This is verified by the cross correlation analysis,[14] which shows high one and two period positive cross correlations between the alumina and aluminium prices.

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[13] See Figure C.1 in appendix C
[14] See tables C.1 and C.2 in appendix C.

Table 3 : Granger Causality test on the alumina and aluminium prices						
lag length	Levels		Logs		Returns	
	$p_y \rightarrow p_a$	$p_a \rightarrow p_y$	$p_y \rightarrow p_a$	$p_a \rightarrow p_y$	$p_y \rightarrow p_a$	$p_a \rightarrow p_y$
1	***$F_{16,15}$=19.24 (0.074%)*** **	**$F_{16,15}$=8.39 (1.24%)***	**$F_{15,14}$=39.40 (0.00%)****	**$F_{15,14}$=14.95 (0.2%)****	**$F_{15,14}$=7.82 (1.61%)***	**$F_{15,14}$=5.82 (3.27%)***
2	**$F_{15,13}$=5.81 (2.11%)***	$F_{15,13}$=3.79 (5.95%)	**$F_{14,12}$=5.44 (2.82%)***	$F_{14,12}$=3.25 (8.64%)	**$F_{14,12}$=5.32 (2.98%)***	$F_{14,12}$=2.39 (14.68%)
3	$F_{14,11}$=3.37 (8.37%)	$F_{16,15}$=1.82 (23.12%)	$F_{13,10}$=2.20 (18.81%)	$F_{13,10}$=1.42 (32.17%)	$F_{13,10}$=2.96 (11.94%)	$F_{13,10}$=3.31 (9.87%)
4	$F_{13,9}$=2.53 (19.47%)	$F_{13,9}$=1.85 (28.28%)	$F_{12,8}$=1.79 (32.87%)	$F_{12,8}$=1.66 (35.13%)	$F_{12,8}$=0.95 (53.76%)	$F_{12,8}$=1.69 (34.69%)
The table gives the outcome of Granger-causality tests on the aluminium and alumina prices. Tail probabilities are given in brackets. Significant outcomes at the 95% level are indicated in bold face. *denotes statistical significance at the 95 percent level of confidence ** denotes statistical significance at the 99 level of confidence						

The next step is to determine whether the causality relation goes from input prices to output prices or vice-versa. I have performed a Granger-causality test using price levels, logs and price returns.[15] The results (see table 3) are somewhat sensitive to the lag length used.[16] If we take a lag length of one as being optimal we see evidence of causality in both directions at the 5% significance level, and stronger evidence of causality from output price to the alumina price at the 1% level. There are three causality effects in this direction which are significant at the 1% significance level as opposed to one significant effect in the opposite direction. Taking a preferred lag length of two, one can see that there is also stronger evidence of Granger-causality from output price to alumina price than from alumina price to aluminium price. There is evidence of causality from output prices to input prices at the 5% significance level under all three specifications. On the other hand there is only evidence of causality from alumina prices to output prices at the 10% level when levels or logs are taken.

[15] I have performed Dickey Fuller tests for all of our variables. The results (presented in appendix 4.B) are inconclusive due to lack of sufficient observations.

[16] The literature on Granger-causality tests highlight the importance of examining robustness to avoid spurious outcomes.

In the light of these results, I characterize the alumina input and output relationship by the following error correction model:[17]

$$\Delta \log p_{at} = \alpha_0 + \alpha_1 \Delta \log p_{yt-1} + \alpha_2 \log\left(\frac{p_{a,t-1}}{p_{y,t-1}}\right) \qquad (6)$$

Regression results and diagnostics, given in table 4.4, confirm the view that equation (6) provides a good representation of alumina price determination.

Table 4: The Estimated Alumina Equation

Variable log p_a	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
α_0	-0.860469	0.138750	-6.201581	0.0000
α_1	0.251991	0.072820	3.460486	0.0042
α_2	-0.450013	0.072736	-6.186905	0.0000
SE of regression	*0.060101*	*LM test (F-statistic)* *Prob(F-statistic)*	*Heteroskedast. (Fstatistic)* *Prob(F-statistic)*	*0.15224* *(0.8661)*
R-squared	*0.774267*			*0.9597* *0.4669*
Durbin-Watson stat	*1.502508*	*Prob(F-statistic)*		*0.000063*

The table gives the OLS estimates of the alumina demand equation (4.6). are given in parentheses.

4.2.The effect of aluminium prices on power prices

I follow the same procedure with power prices. The pattern followed by the annual aluminium price and power price series suggests that they have a positive relationship. This is supported by a cross correlation analysis, which shows high positive contemporaneous and lagged correlations.[18]. Granger-causality results (see table 4.5) show weak evidence of Granger-causality from power prices to aluminium prices as we have just one significant effect only when for lag length of three. However there no

[17] Note that we justify our modeling of alumina, power and aluminium price relationships by showing that the three set of prices are cointegrated, Our Johansen-test cointegration results are presented in table 4.B.2 in the Appendix 4.B.

[18] See fig 4.C.4.2 and tables 4.C.4.4 and 4.C.4.5 in appendix 4.C

evidence of causality in the reverse direction. Our results however are very sensitive to the choice of lag length.

Table 5: Granger causality results power and aluminium price						
lag length	Levels		Logs		Returns	
	$p_y \rightarrow p_E$	$p_E \rightarrow p_y$	$p_y \rightarrow p_E$	$p_E \rightarrow p_y$	$p_y \rightarrow p_E$	$p_E \rightarrow p_y$
1	$F_{16,15}$=1.14 (30.48%)	$F_{16,15}$=0.88 (36.42%)	$F_{15,14}$=3.55 (8.37%)	$F_{15,14}$=4.41 (5.73%)	$F_{15,14}$=0.06 (93.5%)	$F_{15,14}$=0.02 (86.67%)
2	$F_{15,13}$=0.95 (41.62%)	$F_{15,13}$=2.93 (9.92%)	$F_{14,12}$=0.44 (65.51%)	$F_{14,12}$=1.51 (27.13%)	$F_{14,12}$=0.56 (58.76%)	$F_{14,12}$=0.32 (73.30%)
3	$F_{14,11}$=0.59 (63.78%)	***$F_{16,15}$=5.14 (3.44%)****	$F_{13,10}$=0.19 (89.41%)	$F_{13,10}$=2.41 (16.50%)	$F_{13,10}$=0.44 (72.85%)	$F_{13,10}$=1.74 (25.70%)
4	$F_{13,9}$=1.93 (26.84%)	$F_{13,9}$=4.64 (8.31%)	$F_{12,8}$=0.68 (64.95%)	$F_{12,8}$=2.73 (21.74%)	$F_{12,8}$=0.63 (67.19%)	$F_{12,8}$=2.84 (20.84%)

The table gives the outcome of Granger-causality tests on the aluminium and alumina prices. Tail probabilities are given in brackets. Significant outcomes at the 95% level are indicated in bold face.
*denotes statistical significance at the 95 percent level of confidence
** denotes statistical significance at the 99 level of confidence

The relationship between the output and electricity prices is specified as

$$\Delta \log p_E = \beta_0 + \beta_1 \Delta \log p_y + \beta_2 \log p_{E,t-1} + \beta_3 \log p_{y,t-1} \quad (7)$$

The results from estimating (7) show that changes in current power prices are highly dependent on current aluminium prices and lagged discrepancies from their long run relationship (see table 6)

Table 6: the power price equation

Variable Log p_E	Coefficient	Std. Error	t-Statistic	Prob.
β_0	-0.153187	0.383686	-0.399249	0.6967
β_1	0.285026	0.042327	6.733886	0.0000
β_2	0.211959	0.047380	4.473618	0.0008
β_3	-0.472453	0.142966	-3.304657	0.0063
SE of regression	0.03201	LM test (F-statistic)[19] Prob(F-statistic)	0.131275 0.08785	
R-squared	0.854083	Heterosked. (F-statistic)Prob (F-statistic)	1.8992 0.1858	
Durbin-Watson stat	2.027171	Prob(F-statistic)	0.000026	

The table gives the OLS estimates of the electricity demand equation (4.7). Probability values are given in parentheses.

[19] Note that for the LM test in both equations we use a lag length of 2 and results are robust to an increase of the lag length

5. The long run price-cost relationship: the investment equation

I have argued that investment in new capacity governs the long run relationship between price and cost in aluminium smelting. Using the fact that the aluminium industry is highly concentrated, I have constructed a measure for Tobin's q (see Tobin 1987 and Shiller 1990). I estimate q as the ratio a weighted average of the share prices of the major aluminium producers, to the cost of capital in the industry. Share prices directly reflect current and anticipated prices of the aluminium metal, so the expectation of a high future price-cost margin translates directly into higher investment. An increase in the exogenous component of costs reduces q and thus eventually results in lower supply and higher prices.

Investment is therefore and increasing function of q also denoted as the 'shadow price of capital'. It is optimal for the firm to invest until the marginal cost equals the marginal return. At the margin the firm equates the value of an addition to the capital stock with its marginal cost, which rises with the rate of investment. It is optimal to incur the higher marginal cost of investing only when the shadow value of capital is higher than its cost.

Investment is modelled in a rational expectations framework[20] where

$$I_t = \gamma_0 + \gamma_1 \pi_{t-1} + \gamma_2 \Delta q_t + \gamma_4 I_{t-1} + \varepsilon_t \qquad (9)$$

where :

$$q = \frac{S}{Ck} \qquad (9.1)$$

S = average share price

C_k = cost of capital and

$$\pi_t = \frac{p_{Al}}{\hat{C}}{}^{21} \qquad (9.2)$$

[20] I assume that investors make their decisions on the basis of current share prices which in turn are based on rational expectations of future corporate cashflows.

[21] This is a variable measuring profit determined by the ratio of aluminium price to fitted cost. We expect profits to be significant in explaining investment, and be able to derive a long run relationship from cost to prices.

The cost of capital is defined as

$$K_c = m\left(R + \delta - \frac{\Delta m^e}{m}\right) \text{ where} \qquad (9.3)$$

m is the cost of machinery

R is the nominal interest rate (US 3 year government bond rate, IMF, *International Financial Statistics*, September 2000)

δ is the depreciation rate which we assume to be constant at 5%,[22] and

$$\overset{\bullet}{m}^{e} = E\left(\frac{\Delta m_{t+1}}{m_t}\right) \qquad (9.4)$$

is an estimate for the rate of inflation in the price of machinery.

I have used Δq as explanatory variable instead of q as the consequence of apparent non-stationarity of q arising out of the trend in nominal interest rates over the sample period.[23] The change in machinery price $\frac{\Delta m^e}{m}$ is modelled adaptively so that the expected rate of inflation for machinery is explained on the basis of the discrepancy between the last years predicted and current inflation value and the actual outcome – see Harvey (1981, pp.229-30).

$$\Delta \ln m_t^e = \alpha \Delta \ln m_{t-1}^e + (1-\alpha)\Delta \ln m_{t-1} \qquad (9.5)$$

which may be written as

$$\Delta \ln m_t^e = (1-\alpha)\sum_{i=1}^{\infty} \alpha^i \Delta \ln m_{t-i} \qquad (9.6)$$

I take the value α=0.5 truncating the distribution at 6.The cost of capital is thus estimated using the calculated values from equation 9.3 a depreciation rate of 5%.

Ideally, in order to get an estimate of the average share price in the aluminium industry, one should average the share prices across the six dominant players: Alcoa (USA) Alcan (Canada), Pechiney (France), Reynolds (USA), Kaiser (USA) and Alusuisse (Switzerland) . The big six produced 60% of the world total in 1975 50% in 1984 and 42.4% in 1990. Concentration decreased over the years but it still remains with a few companies controlling a large proportion of global output. Because Alussuise lost most of its status in the industry between 1955 and 1987 I have not considered its

[22] This figure was reported by an aluminium industry consultant who estimated that the depreciation rate for aluminum smelters is linear on a 20 year basis.

[23] See figures D.1 and D.2 (appendix D).

share price as being representative for the period I analyze. Pechiney was publicly owned until 1995, so share prices are only available after this date. Lastly, because Kaiser was taken over by the Maxxam group in the late eighties, its share prices are not available after that period. This leaves me with three continuous series of share prices corresponding to Alcoa, Alcan and Reynolds. Taken together, these three firms control 30% of the world aluminium production (see table 1.3 p11). In order to get an estimate of the average aluminium share price I have taken the average share price of these three companies weighting the individual quotations by the inverse of their volatilities. Higher volatility of share prices indicates that investors expect higher risk over future earnings which suggests a lower degree of precision in the estimates (see Parakevopoulos, 2000).

Results from estimating equation (.9) are reported in table (6). These show that current changes in q and the price-cost margin are very significant in explaining investment.

Table 6: The Estimated Investment Relationship

Variable Investment	Coefficient	Std. Error	t-Statistic	Prob.
γ_0	-0.069218	0.027446	-2.522002	0.0284
γ_1	0.028139	0.011812	2.382356	0.0363
γ_2	0.001687	0.000833	2.025699	0.0677
γ_3	-2.05E-06	1.12E-05	-0.183771	0.8575
SE of regression	*0.020368*	*LM test*[24] *(F-statistic)*		*0.1173*
		Prob (F-statistic)		*0.8907*
R-squared	*0.493755*	*Heterosked. (F-statitic)*		*0.8907*
		Prob (F-statistic)		*0.7721*
		Prob(F-statistic)		
Durbin-Watson stat	*1.882863*			*0.050398*

The table gives the OLS estimates of the investment equation (4.9). Probability values are given in parentheses.

This is an important finding as it provides with a link between average variable cost and investment defined as the change capacity. In the next section I close the model by developing a framework in which capacity is linked to the demand and supply functions within aluminium smelting. This is done in order to explain the nature of the long run relationship between cost and prices.

[24] The lag length used for the LM residual correlation test is 2. Results are robust to the extension of the lag length.

6. Closing the model: the demand and supply relationships

In order to close the model I set up a framework in which the price setting behaviour represented via supply and demand equations. Price is linked to the production structure through investment in new smelting capacity. The inverse demand function is specified in equation 4.10 in which the aluminium price is defined as a function of its own lag and the output gap between consumption on the one hand and capacity and lagged production on the other.

$$\log(p_{y_t}) = \kappa_0 + \kappa_1 \log cons_t + \kappa_2 \log cap_t + k_3 \log y_{t-1} + k_4 \log p_{y,t-1} \qquad (10)$$

Estimation results, reported in table 7, show all the estimated coefficients to be highly significant. The inverse demand equation may be interpreted with the investment equation 9 to see that high input cost leads to lower investment in new capacity, which in turn leads to higher prices. For a 1% decrease in capacity we expect prices to rise by 3.17%. Higher current consumption also leads to higher prices and lower levels of past production also lead to upwards price pressure.

Table 7: The Estimated Aluminium Price Equation

Variable log p_y	Coefficient	Std. Error	t-Statistic	Prob.
κ_0	20.55036	5.446106	3.773404	0.0031
κ_1	3.393012	0.858660	3.951522	0.0023
κ_2	-3.170838	1.120685	-2.829375	0.0164
κ_3	-1.842486	0.756808	-2.434550	0.0331
κ_4	0.435922	0.172331	2.529562	0.0280
SE of regression	*0.147562*	*LM (F-statistic)*		*0.5637*
		Prob (F-statistic)		*0.7721*
R-squared	*0.690646*	*Heterosked. (F-statistic)*		*0.8366*
Durbin-Watson stat	*1.538292*	*Prob (F-statistic)*		*0.007562*
		Prob(F-statistic)		

The table gives the OLS estimates of the investment equation (4.10). Probability values are given in parentheses.

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The consumption variable is endogenized in equation (11) to take into account that, because aluminium is an intermediate product used as input by industrial producers, so its consumption depends on its price as well as the quantity of industry output production. Current price changes affect consumption only in the following period as producers respond to price changes by retooling the investment process. I therefore model consumption with the following equation:

$$\log(Cons) = \lambda_0 + \lambda_1 \log(inprod) + \lambda_2 \log(p_{AL,t-1}) \quad (4)$$

Estimation results are reported in table 4.8. Both estimated coefficients are significant and have the expected sign. They imply that for every 1% increase in industrial production consumption to rise by 1.53%. Conversely if prices rise by 1% consumption next will be expected to drop by 0.13% in the next period.

Table 8: Estimated Consumption Equation

Variable log cons	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
λ_0	3.663634	0.349056	10.49583	0.0000
λ_1	1.527074	0.090536	16.86695	0.0000
λ_2	-0.131037	0.037494	-3.494842	0.0040
SE of regression	*0.030516*	*LM(2) F-statistic*[25]		*2.0579*
		Prob (F-statistic)		*0.0278*
R-squared	*0.961930*	*Heteroskedast. (F-statistic)*		*1.3858*
				0.3012
Adjusted R-squared	*0.956073*	*Prob (F -statistic)*		*0.00000*

The table gives the OLS estimates of the consumption equation (11). Probability values are given in parentheses.

Finally we set up the supply schedule in which production is restricted to be autoregressive, and also dependent on capacity and one period lagged prices.

$$\log y_t = \mu_0 + \mu_1 \log cap_t + (1-\mu_1)\log y_{t-1} + \mu_2 \log p_{y,t-1} \quad (12)$$

Results from estimating (4.12) which are presented in table 4.9. Accordingly, we should expect production to rise by 0.53% when capacity increases by 1%. Moreover if prices rise by 1% we should expect next period production to rise by 0.10%.

[25] Note that this result is not robust to the extension off lags as LM(5) F=2.0579 (0.1739)

Table 9: Estimated Production Equation				
Variable log y_t	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
μ_0	-0.964834	0.275043	-3.507941	0.0039
μ_1	0.532001	0.131632	4.041589	0.0014
μ_2	0.106327	0.034186	3.110228	0.0083
SE of regression	*0.030212*	*LM(2) F-statistic*		*0.3665*
		Prob (F-statistic)		*0.7013*
R-squared	*0.937042*	*Heterosked. (F-statistic)*		*9.553536*
		Prb (F-statistic)		*0.3505*
Adjusted R-squared	*0.927356*	*Prob (F-statistic)*		
The table gives the OLS estimates of the production equation (4.12). Probability values are given in parentheses.				

In this section have closed the model by providing a demand and supply framework consisting of three equations determining output price, consumption and production respectively. These have been linked to the firm level model through investment which is determined by changes in production capacity. The purpose of this section has been to provide a complete model of the aluminium cost and price setting structure, in which the long run relationship between cost and prices is determined through investment in new smelter capacity.

7. Concluding remarks

It has been argued that, over the course of the nineteen eighties, aluminium producers lost their ability to control prices and as a result they could no longer fix prices as a mark-up over marginal cost. This prompts the question of whether the main producing companies are no longer highly profitable. Long run price trends have been lower in real terms, but producers have since responded to the increased international competition by focusing on cutting costs through economies of scale, mergers acquisitions and technological improvement. The purpose of this paper has been to shed light to this issue by determining the relationship between cost and prices within aluminium smelting.

I have specified a model to determine the relationship between cost and prices within aluminium smelting. Aluminium producers are seen as cost-minimizing price takers reflecting the fact that, since the mid nineteen eighties, aluminium has world wide been priced on the basis of the LME quotations. The central component of the model is a translog cost function to allow for conditional input demands to vary over time. The model also reflects the prevalent industry practice of risk sharing agreements between aluminium smelters and the providers of (energy and alumina) inputs shows that as a consequence, there is a strong short term link from the aluminium prices to production costs, reversing the textbook paradigm. The implications is that cost do not determine prices in the short run, implying that producers do not have control to increase their prices in the face of higher production cost. This in turn explains why profitability might have been lower in the last decade.

Costs affect prices only indirectly through investment in new smelting capacity. This is shown in our model through investment relationship relating profitability and Tobin's q to the rate of investment. The model has been closed with demand and supply relationships illustrating the market behaviour.

The results from this paper may be summarised as follows:

1. The translog model gives us best fitting estimates of the average variable cost and the conditional input demands. It does not appear possible to restrict factor substitution patterns.
2. In a framework where investment is modelled as function of Tobin's q and a measure of profit, costs are reflected in prices in the long run via investment in new smelter capacity.

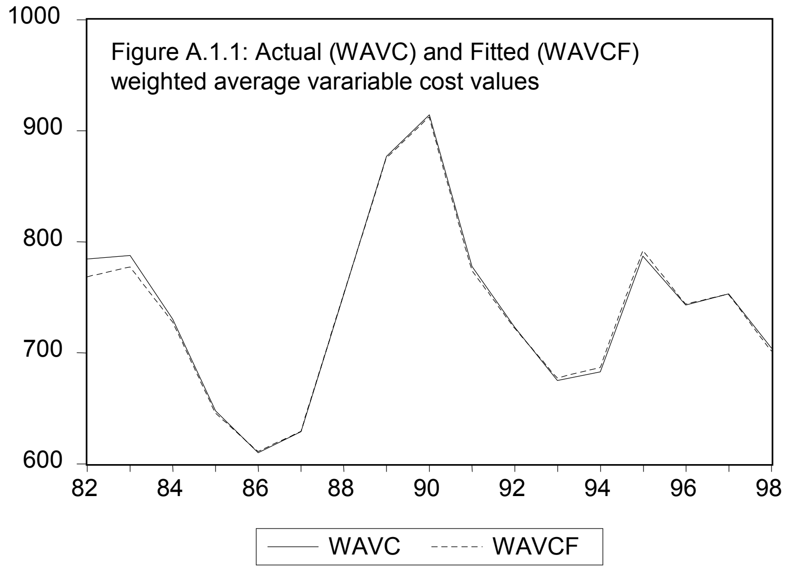
The main motivation of this work has been to reflect the structural changes that have characterized the aluminium industry over the last few decades. I order to capture the changes in competition I have estimated cost and related it to output prices by illustrating the effect of the prevalent industry risk sharing agreements. Previous studies of the aluminium industry had often used unreliable measures of weighted average variable cost. The main contribution of this work lies on the estimation of cost applying the flexible translog framework o a unique set of proprietary data.

An interesting extension to this study lies on the investigation of the effects of the recent ongoing consolidation taking place within the aluminium industry. In the year 2000 three important mergers have been completed (see p. 85) meaning that the industry moves back towards a highly concentrated structure. Two important questions arise which I hope to answer in future research.

1) Is the “re-concentration” process going to change the system of cost-cutting incentives enforced by the centralization of LME trading?
2) Given that the main players will no longer be able to control prices directly, will they choose play output setting games in order to indirectly set prices?

Appendix A

A.1. Actual and fitted weighted average variable cost and conditional input demands



A.1 Actual and fitted conditional input demands

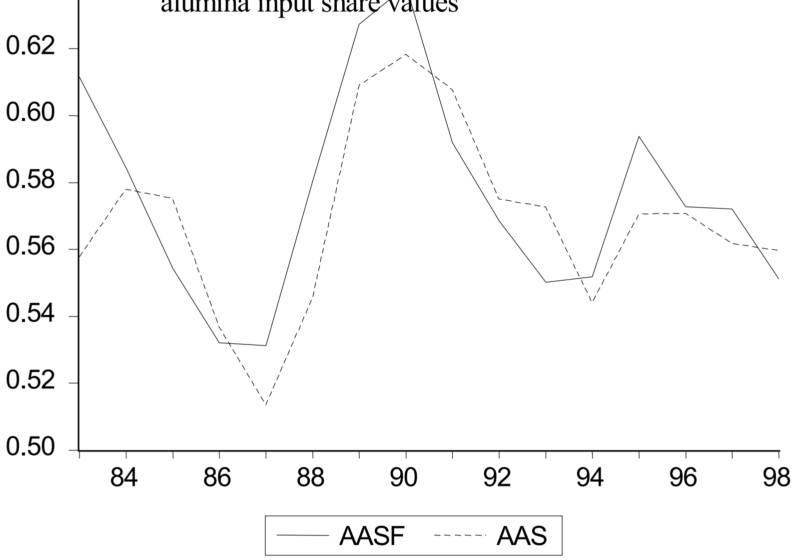


Figure A.1.2: Actual (AAS) and fitted (AASF) alumina input share values

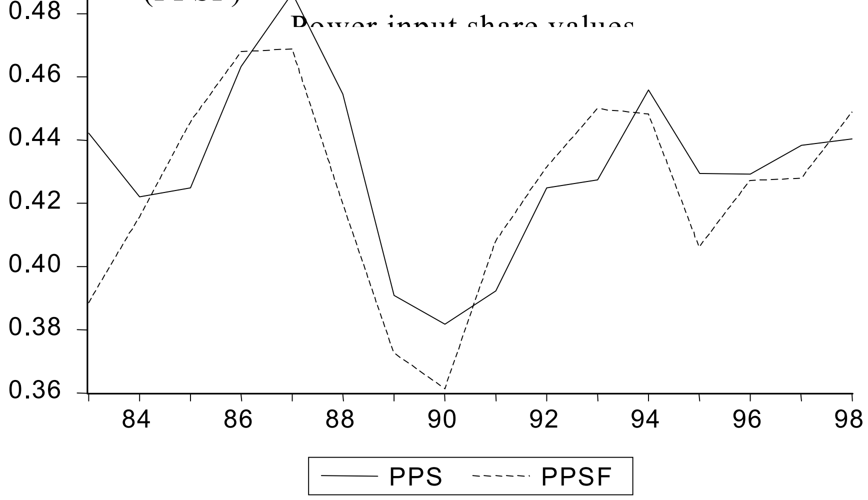
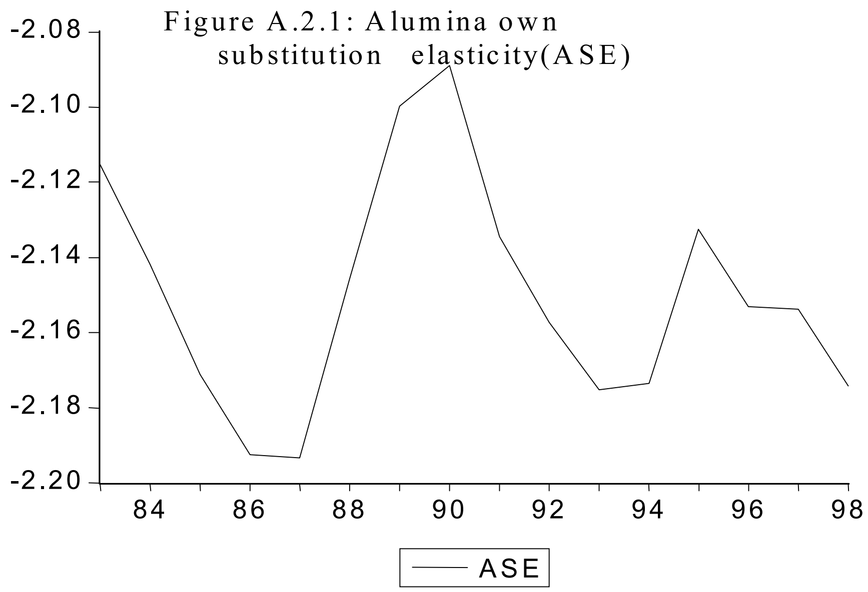
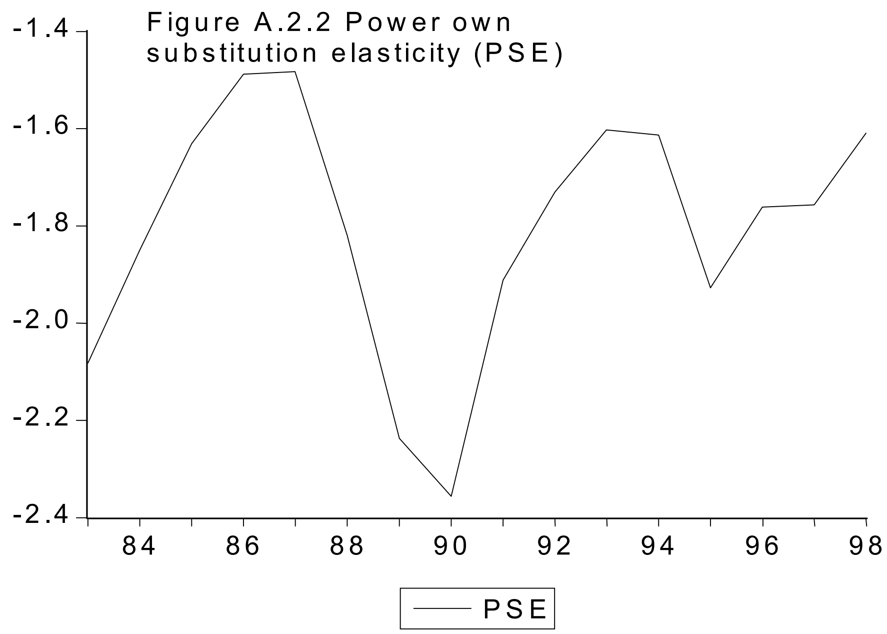


Figure A.1.3 : Actual (PPS) and Fitted (PPSF) Power input share values

A.2 Substitution elasticities





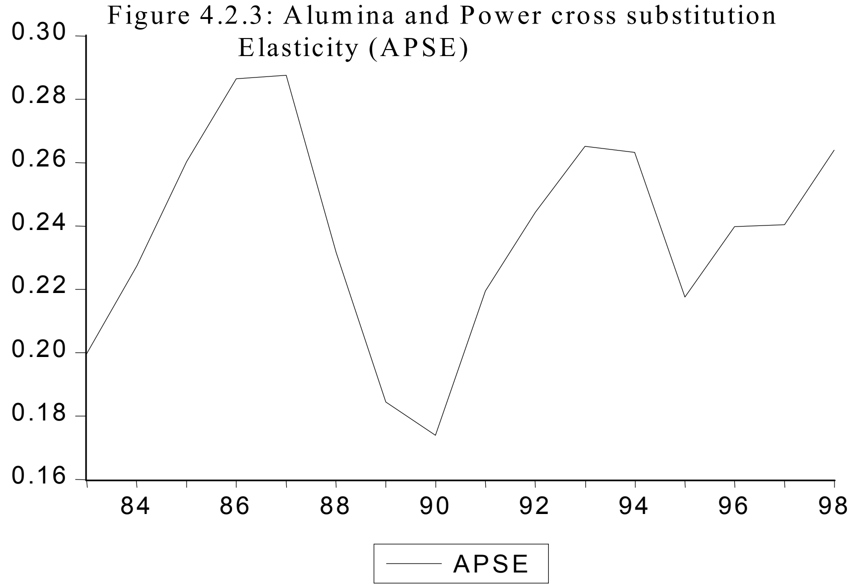


Figure 4.2.3: Alumina and Power cross substitution Elasticity (APSE)

A.3 Price elasticities

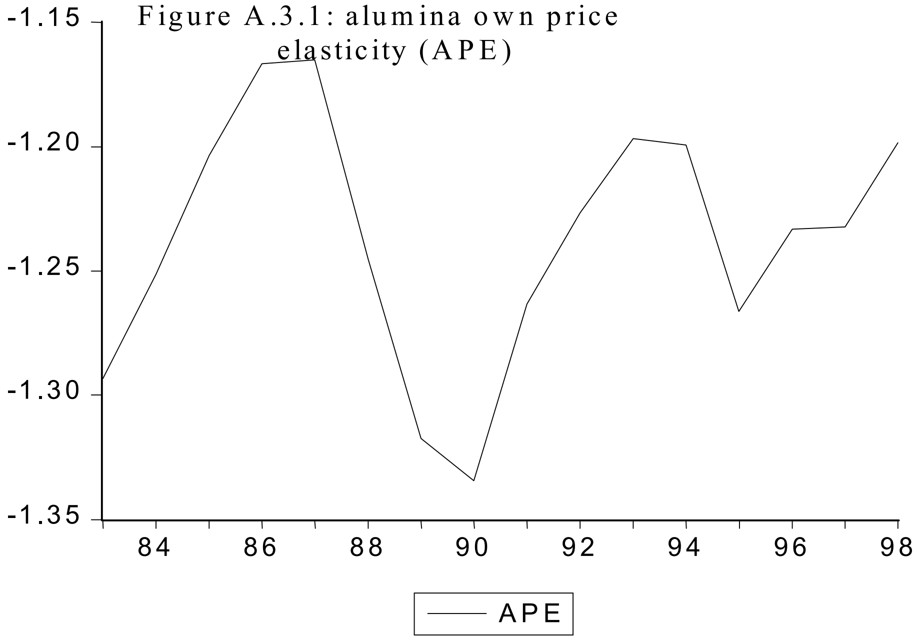


Figure A.3.1: alumina own price elasticity (APE)

Figure A.3.2:Alumina and Power cross price elasticity

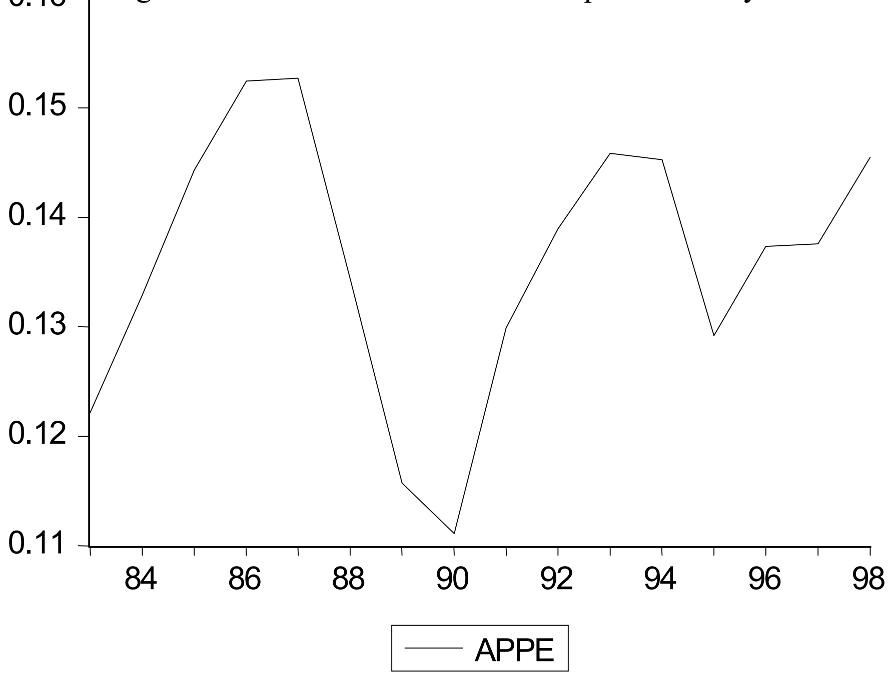
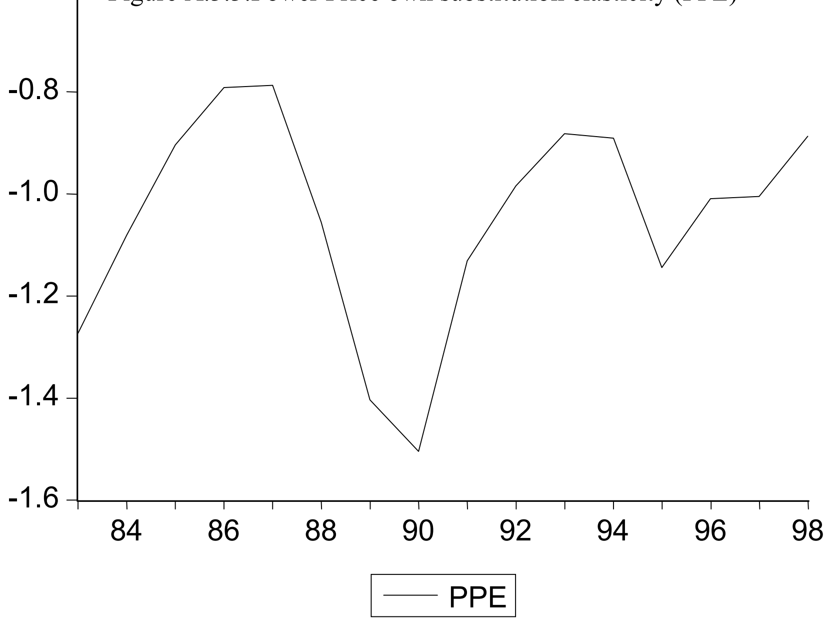


Figure A.3.3:Power Price own substitution elasticity (PPE)



Appendix B

Table B.1: Dickey Fuller test results[26]

	Levels					***Differences***				
Lag length	1	2	3	4	5	1	2	3	4	5
P_y[27]	-2.52	-2.71*	-2.71*	-2.72*	-3.12*	-2.79*	-2.91	-2.30	-1.64	-6.25***
P_A	-3.78**	-2.77*	-1.78	-1.58	-2.40	-3.03*	-3.56**	-2.90*	-1.54	-1.11
P_E	-2.88*	-4.07***	-3.09*	-2.26	-2.40	-2.34	-4.36***	-5.51***	-2.66	-2.59
c	-0.396	-0.28	-0.34	-0.12	0.48	-3.41**	-2.48	-3.27**	-2.10	-2.25
y	-1.32	-0.15	-1.39	-1.63	-0.98	-3.65**	-2.18	-1.50	-1.63	-2.01
cap	0.82	0.82	0.42	0.54	0.48	-2.40	-1.97	-1.87	-1.82	-2.34
I	-2.40	-1.97	-1.87	-1.82	-2.34	-4.69***	-2.66	-2.00	-2.00	-2.00

Where:

P_y is the aluminium price

P_A the price of alumina

P_E is the price of power electricity

C is consumption

Y is production

Cap is capacity

I is investment measured as the change in capacity

[26] * stands for significance at the 10% level
** stands for significance at the 5% level
*** stands for significance at the 1% level

Table B.2 cointegration results

Eigenvalue	Likelihood Ratio	5 Percent Critical Value	1 Percent Critical Value	Hypothesized No. of CE(s)
0.951661	54.58417	29.68	35.65	None **
0.558037	15.20046	15.41	20.04	At most 1
0.297237	4.585567	3.76	6.65	At most 2 *

*(**) denotes rejection of the hypothesis at 5%(1%) significance level
L.R. test indicates 1 cointegrating equation(s) at 5% significance level

Unnormalized Cointegrating Coefficients:

p_a	p_y	p_E
0.002271	-0.001141	0.140005
0.008740	0.000577	-0.405034
0.010510	5.50E-05	0.033895

Normalized Cointegrating Coefficients: 1 Cointegrating Equation(s)

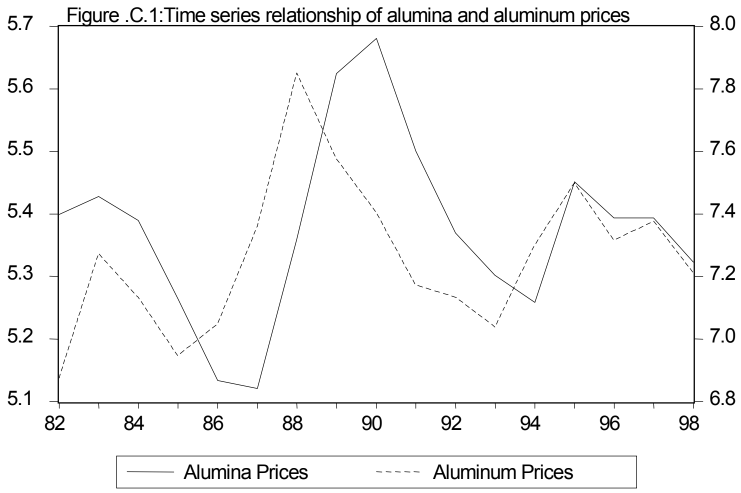
p_a	p_y	p_E	C
1.000000	-0.502562	61.64752	-629.9582
	(0.20072)	(30.9911)	
Log likelihood	-141.0430		

Normalized Cointegrating Coefficients: 2 Cointegrating Equation(s)

p_a	p_y	p_E	C
1.000000	0.000000	-33.79848	431.3541
		(10.0551)	
0.000000	1.000000	-189.9189	2111.804
		(27.7112)	
Log likelihood	-135.7355		

Appendix C

C.1 The relationship between aluminium price and alumina price



C.1.1. Cross correlation analysis

Table C.1: cross correlation analysis alumina and output price (returns)

$R_a, R_{y,t-j}$	$R_a, R_{y,t+j}$	i	lag	lead
. |*** .		. |*** .		0	0.3311	0.3311
. |*******		*****| .		1	0.6553	-0.4659
. |****.		.****| .		2	0.3601	-0.4418
. **| .		.****| .		3	-0.1972	-0.4097
*****| .		.	.		4	-0.4934	0.0486
. *| .		. |*** .		5	-0.1030	0.3499

Table C. 2: cross correlation analysis alumina and output price (logs)

$\ln p_a, \ln p_{y,t-i}$	$\ln p_a, \ln p_{y,t+i}$	i	lag	lead
. |*** . |	. |*** . |	0	0.3357	0.3357
. |******** |	.****| . |	1	0.7493	-0.3512
. |****** |	*******| . |	2	0.6353	-0.6466
. |** . |	******| . |	3	0.1803	-0.5546
. **| . |	. *| . |	4	-0.1725	-0.0962
. **| . |	. |*** . |	5	-0.2121	0.3021

C.2. The relationship between power and aluminium prices

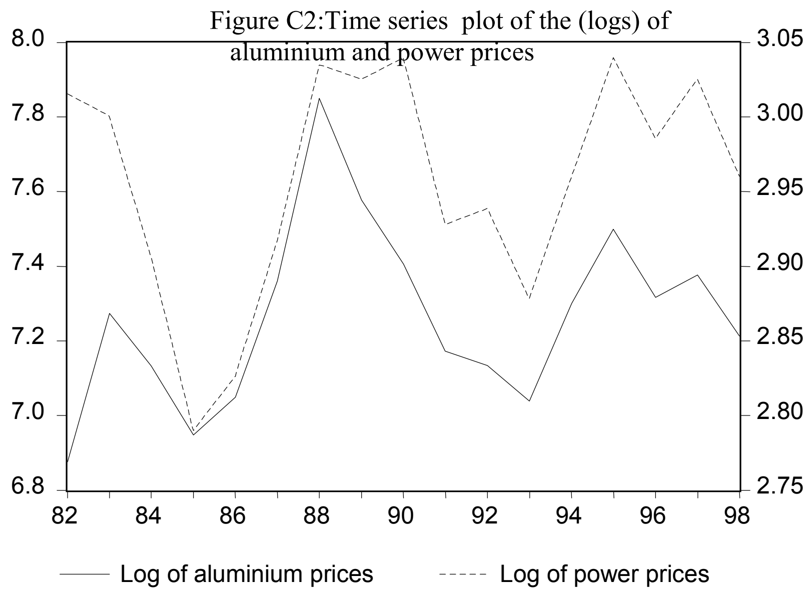


Figure C2:Time series plot of the (logs) of aluminium and power prices

Table C.3: cross correlation analysis power and aluminium price (returns)				
$R_E, R_{y,t-j}$	$R_E, R_{y,t+j}$	i	lag	lead
. |******** |	. |******** |	0	0.7710	0.7710
. |* . |	. | . |	1	0.0761	0.0275
. *| . |	. ***| . |	2	-0.0558	-0.2488
. ***| . |	******| . |	3	-0.3126	-0.6079
. **| . |	. ***| . |	4	-0.1593	-0.3151
. *| . |	. |** . |	5	-0.0431	0.1753

Table C.4 : Cross correlation analysis power and aluminium price(logs)				
$\ln p_E, \ln p_{y,t-i}$	$\ln p_E, \ln p_{y,t+i}$	i	lag	lead
. |******* |	. |******* |	0	0.6540	0.6540
. |** . |	. |***** |	1	0.1609	0.5073
.****| . |	. |*** . |	2	-0.4304	0.2730
********| . |	. | . |	3	-0.7684	-0.0362
*****| . |	. **| . |	4	-0.4923	-0.2175
. | . |	. **| . |	5	0.0472	-0.2068

Appendix D

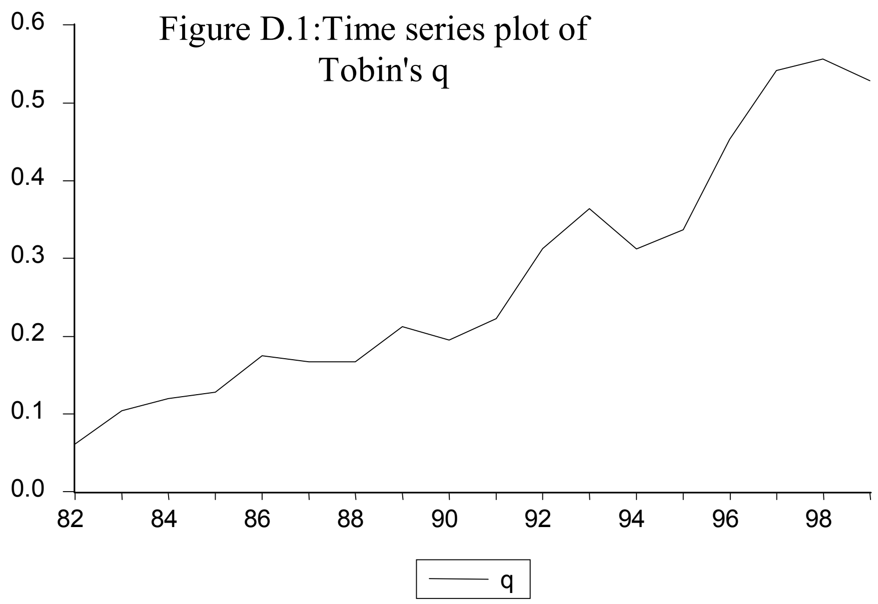


Figure D.1:Time series plot of Tobin's q

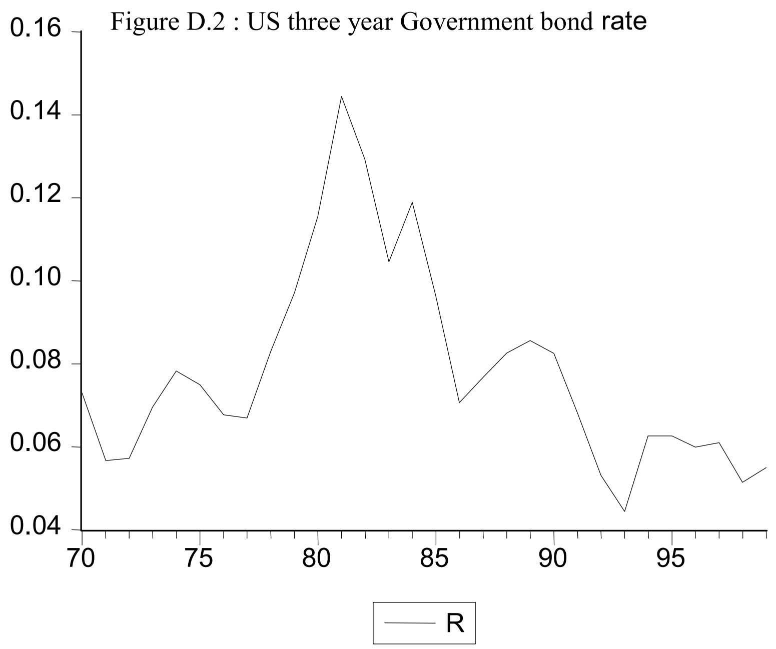


Figure D.2 : US three year Government bond rate

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