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Testing for Market Power in the Norwegian Primary Aluminium Industry

Discussion Papers

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Abstract:
The hypothesis of market power in the Norwegian primary aluminium industry is tested using plant-level panel data. Economies of scale are found to be present, and Norwegian aluminium plants charge a procyclical price-cost margin that significantly exceeds zero. Consequently, the simple competitive hypothesis is rejected. The hypothesis that products are differentiated is not rejected, since several plants are found to charge a price permanently over the world market price. A decline in industry concentration internationally, which is assumed to increase the degree of competition, has no significant effect on the price-cost margins of Norwegian plants.

Keywords: Market power; Differentiated products; Aluminium industry

JEL classification: C23, D21, D43, L61

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1. Introduction

This paper uses plant-level panel data to test for the existence of market power in the Norwegian primary aluminium industry. Market power, defined as a positive price-cost margin, may be due to oligopolistic behaviour, product differentiation or economies of scale.

According to Rønning et al. (1986), the international aluminium industry was dominated by a few large companies during the first post-war decades. In this oligopoly setting, the price was set to cover costs plus a margin, that is a producer price-based system, and stock adjustments were used to meet demand cycles. The price was kept relatively low during periods of excess demand, at least in the 1950s, to attract new consumers, cf. Rosenbaum (1989). Concentration has declined over time, however. While the six dominant companies, Alcan (Canada), Alcoa (USA), Alusuisse (Switzerland), Kaiser (USA), Pechiney (France) and Reynolds (USA), accounted for 86 per cent of world capacity in 1955, they accounted for 73 per cent in 1971, 62 per cent in 1979, and 40 per cent in 1993.[1] Fringe plants had a significant impact on price determination as early as the mid-seventies, and the industry changed to be more competitive and less oligopolistic, cf. Reynolds (1986, p. 231). Primary aluminium has been traded at the London Metal Exchange (LME) since 1978 and at the Commodity Exchange in New York (COMEX) since 1981. And today, the price development at LME and COMEX is of major importance to most trade in aluminium.

Physically, aluminium ingot is a homogeneous good at a given grade of purity. A comparison of the price per tonne aluminium obtained by Norwegian aluminium plants and the spot market price registered at LME of 99.7 per cent ingot aluminium reveals important price variation, however. These price differences may reflect (see also Klette (1990)):

(i) Vertical (quality) differentiation, that is, variation in the purity of aluminium offered from different plants;
(ii) Horizontal differentiation, for example due to semi-manufactures, customer tailored products, and variation in customer service and reliability of delivery across plants.

[1] Sources: Bresnahan and Suslow (1989, p. 280) and information provided by Hydro Aluminium, Oslo.

(iii) Vertical integration between producers and buyers of primary aluminium and semi-manufactures;

(iv) The extensive use of long-term contracts made by Norwegian aluminium plants at different points in time and with different price agreements.

Although all these factors may be present, their relative importance is unknown. While (i) and (ii) imply that Norwegian aluminium prices may permanently differ from the spot market prices, (iv) implies that Norwegian aluminium prices should equal the spot market price in the long-run. They may lag behind though. The effect of (iii) depends on the companies' internal pricing strategies.

The flexible translog cost function approach, suggested by Christensen et al. (1971, 1973), is used to estimate the variable cost functions of Norwegian aluminium plants. Support is found for increasing returns to scale with respect to variable inputs, and the paper concludes that Norwegian aluminium plants charge a procyclical price-cost margin that significantly exceeds zero. Consequently, the simple competitive hypothesis is rejected. Heterogeneity in both prices and marginal costs gives rise to intra-industry variation in the margins.

Regressions of Norwegian prices on the spot market price are run, and long-run price homogeneity is supported by the data. The interpretation of this is that the observed price differences are, to a large degree, explained by the use of long-term contracts. However, the hypothesis of differentiated products is not rejected, since several plants are found to charge a price permanently above the spot market price. A decline in industry concentration internationally, which is assumed to increase the degree of competition, has no significant effect on the price-cost margins of Norwegian plants during the seventies and eighties.

Section two discusses the theoretical framework, while section three and four present the estimated variable cost function and the price-cost margins respectively. The main findings are summarized in the final section.

2. The theoretical framework

This section presents the differentiated products and the homogeneous goods oligopoly model with competition in quantities.[2] The Norwegian primary aluminium industry is dominated by two companies, Hydro Aluminium and Elkem aluminium. We assume, however, that variable input decisions are taken at the plant level, and that each plant maximizes own profits. Capacity expansions and output decisions, which are more likely to be taken at the concern level, are not included in this analysis.

If aluminium plants produce *differentiated products*, i.e. products that are imperfect substitutes, the prices may vary across plants. We assume that plants produce either a single product or a stable product mix over time, so that output of each plant may be treated as a single product. Each plant is assumed to face a downward-sloping demand curve, which depends on own-price, the price of other aluminium products, the prices of substitutes for aluminium and the level of activity in the end-use industries of aluminium. Equation (2.1) defines world demand for plant f's product. The inverse demand equation on reduced form is given in (2.1').

(2.1) $X_f = J_f(P_f, P_{-f}, P^*, M)$ $\qquad$ f=1,..,m

(2.1') $P_f = P_f(X_f, X_{-f}, P^*, M)$ $\qquad$ f=1,..,m

where X_f is world demand for aluminium from plant f; P_f is the price of plant f's product; $P_{-f}=(P_1,..,P_{f-1},P_{f+1},..,P_m)$, is a vector of the prices of all other primary aluminium products; $X_{-f}=(X_1,..,X_{f-1},X_{f+1},..,X_m)$, is a vector of output in other plants; P^* is the price of substitutes for aluminium; and M is output in the end-use industries of aluminium. The downward-sloping demand curves assumption implies that $\partial X_f/\partial P_f < 0$, and if own-price derivatives dominate cross-price derivatives, then $\partial P_f/\partial X_f < 0$, f=1,..,m. If, in addition, $\partial X_f/\partial P_j > 0$, see Friedman (1983, p. 52) for this definition of differentiated products, then $\partial P_f/\partial X_j < 0$, f,j=1,..,m.

Equations (2.2) and (2.3) define the variable cost function and the first-order profit maximization condition of plant f, which is consistent with competition in quantities. At the optimum, marginal cost equals (perceived) marginal revenue.

(2.2) $C_f = C_f(Q_f, X_f, K_f)$ $\qquad$ f=1,..,m

[2] The conclusions in section 3 are independent of the assumption that quantity rather than price is the paramount decision variable for our sample.

$$(2.3) \quad P_f\,[1 - \varepsilon_f - \Sigma_{j\neq f}\,\mu_{fj}\cdot\theta^D_{fj}] = \partial C_f(.)/\partial X_f \qquad f=1,..,m$$

where C_f is variable costs of plant f; Q_f is a vector with variable input prices faced by plant f; K_f is the capital stock in plant f; $\varepsilon_f = -[\partial P_f/\partial X_f]\cdot[X_f/P_f] \geq 0$ is the inverse own-price elasticity of demand faced by plant f; $\mu_{fj} = -[\partial P_f/\partial X_j]\cdot[X_j/P_f] \geq 0$ is the inverse cross-price elasticity of demand between product f and j; $\theta^D_{fj} = [\partial X_j/\partial X_f]\cdot[X_f/X_j] \leq 0$ is plant f's conjectural variation elasticity with respect to plant j. This measures the competitive reaction of plant j to plant f's output decision, as perceived by plant f. In a differentiated products oligopoly with strategic interdependence between plants, we assume that each plant's profit is a decreasing function of other plants' quantities. Hence, the conjectural variation elasticities are negative, cf. Tirole (1989, p. 218). If there are no strategic interdependence between plants, the conjectural variation elasticities are zero, and the industry is characterized by monopolistic competition.

If aluminium plants produce *homogeneous goods*, we assume all plants to face the same demand curve; $P_1 =..= P_f =..= P_m \equiv P$ and $\partial P/\partial X_j \equiv \partial P/\partial X$, where $X = \Sigma_f X_f$, f=1,..,m. This provides a basis for testing the relevance of the homogeneous goods hypothesis within the differentiated products model. By taking these restrictions into account, world demand for primary aluminium can be defined as in (2.4), and the plant's first-order condition collapses to (2.5), cf. appendix 2.[3]

$$(2.4) \quad X = J(P, P^*, M)$$
$$(2.5) \quad P\,[1 - \varepsilon\cdot\theta^H_f] = \partial C_f(.)/\partial X_f \qquad f=1,..,m$$

where X is total demand for primary aluminium; P is the price of primary aluminium; $\varepsilon = -[\partial P/\partial X]\cdot[X/P] \geq 0$ is the inverse demand elasticity; $\theta^H_f = [\partial X/\partial X_f]\cdot[X_f/X] \leq 1$ is plant f's conjectural variation elasticity with respect to total supply, which includes f's own output. If the market is characterized by Cournot oligopoly, no strategic interdependence is present, and $\partial X/\partial X_f = 1$. Hence, $\theta^H_f = S_f$, where $S_f = X_f/X$ is the market share of plant f. If the market is competitive so that $\theta^H_f = 0$, we expect price to equal marginal cost, unless economies of scale are present.

The degree of market power exerted by plant f is measured by the price-cost margin, that is, the Lerner index (Lerner (1934)):

$$\mathcal{L}_f = [P_f - \partial C_f(.)/\partial X_f]\,/\,P_f.$$

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[3] The homogeneous goods model is discussed in Appelbaum (1979, 1982).

Standard assumptions imply that $[P_f - \partial C_f(.)/\partial X_f] \geq 0$ and $\partial C_f(.)/\partial X_f \geq 0$, and hence $0 \leq \mathcal{L}_f \leq 1$. When price equals marginal cost and $\mathcal{L}_f = 0$, plant f has no market power. The larger is $\mathcal{L}_f$, the larger is the market power.

Equations (2.6) and (2.7) are the market power indices in the differentiated products model (D) and the homogeneous goods model (H) respectively.

(2.6) $\mathcal{L}_f^D = \varepsilon_f + \Sigma_{j \neq f} \mu_{fj} \cdot \theta_{fj}^D$ f=1,..m

(2.7) $\mathcal{L}_f^H = \varepsilon \cdot \theta_f^H$ f=1,..m

Equations (2.6) and (2.7) demonstrate that a plant's market power is determined by the elasticities of demand and the competitive reactions of other plants. Market power is a decreasing function of own-price elasticity and competitors' reactions in both the differentiated products and the homogeneous goods oligopoly. The less price-sensitive is demand with respect to own-price, that is, the larger is the inverse own-price elasticity, the greater is market power. And, since we assume that the quantity reaction of other plants to plant f's decision is negative, in which case $\theta_{fj}^D < 0$ and $\theta_f^H < 1$, such reactions reduce market power. In the differentiated products case, the magnitude of the cross-price elasticities, the μ_{fj}'s, determine the effect of the competitive reactions of other plants on the market power of plant f.

3. The cost function

Alternative approaches have been applied to test for the existence and sources of market power.[4] This paper obtains a measure of the degree of market power from data on price and estimated variable cost equations, and tests the theoretical predictions of the models in section 2 using the calculated price-cost margins. This direct approach, which is an alternative to estimating all equations determining demand and supply, simplifies the analysis. This is particularly true if the market is a differentiated products oligopoly.[5] The drawback of the direct approach is that it reduces the possibility of making inference about the relative importance of alternative sources of market power.

We model variable costs using the flexible translog function suggested by Christensen et al. (1971, 1973), which can be interpreted as a quadratic approximation to a general continuous twice-differentiable function. Labour (L), raw materials (M) and electricity (E) are assumed to be variable inputs, while capital is treated as a quasi-fixed, or predetermined, factor. Plant-specific dummy variables and a trend variable are included. Hence, the general cost function captures permanent differences in technology or efficiency across plants (fixed effects) as well as technical innovation over time. In their analysis of the aluminium industry in North America, Bresnahan and Suslow (1989) conclude that the industry short-run marginal cost curve is right angled at the capacity constraint. To capture that the marginal cost curve may be particularly steep close to the capacity constraint, we include output multiplied with a dummy variable that is one in periods with a very high capacity utilization ratio and zero elsewhere.

$$
\begin{aligned}
(3.1)\quad \ln C_{ft} = {} & \gamma_{0f} + \Sigma_i\, \alpha_{if} \ln Q_{ift} + 1/2\, \Sigma_i \Sigma_j\, \beta_{ij} \ln Q_{ift} \ln Q_{jft} + \gamma_X \ln X_{ft} + 1/2\, \gamma_{XX} (\ln X_{ft})^2 \\
& + \Sigma_i\, \gamma_{iX} \ln Q_{ift} \ln X_{ft} + \gamma_K \ln K_{ft} + 1/2\, \gamma_{KK} (\ln K_{ft})^2 + \Sigma_i\, \gamma_{iK} \ln Q_{ift} \ln K_{ft} \\
& + \gamma_{XK} \ln X_{ft} \ln K_{ft} + \gamma_T \ln T_t + 1/2\, \gamma_{TT} (\ln T_t)^2 + \Sigma_i\, \gamma_{iT} \ln Q_{ift} \ln T_t \\
& + \gamma_{XT} \ln X_{ft} \ln T_t + \gamma_{KT} \ln K_{ft} \ln T_t + \gamma_{CAP}\, DUM_{ft} \ln X_{ft} + \Sigma_i\, u_{ift} \ln Q_{ift} + u_{ft} \\
& \qquad\qquad i,j = L, M, E,\quad f = 1,..,m
\end{aligned}
$$

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[4] For surveys of this field, see Geroski (1988) and Bresnahan (1989). See also Rotemberg and Woodford (1991) and Chirinko and Fazzari (1994).

[5] An attempt was made to estimate the reduced form price equations. No effects of variations in output of Norwegian plants on their own price or the spot market price of primary aluminium were found. This supports the hypothesis of no market power, cf. Bresnahan (1989, p. 1048-49), and may suggest that Norwegian plants behave as followers and price takers, or that the international aluminium market was relatively competitive over the seventies and eighties. The "high degree of competition" hypothesis is supported by Froeb and Geweke (1987), who find that "the structure and performance in the U.S. aluminum industry in the postwar period conform well with the hypothesis that the primary aluminum market was competitive in the long run".

where subscript t denotes period t. C_f is total variable costs of plant f, that is, $C_f = \Sigma_i Q_{if} \cdot V_{if}$; Q_{if} is the price of input i faced by plant f; V_{if} is the quantity of input i in plant f; X_f is the output of plant f measured in tonnes aluminium; K_f is the output capacity of plant f measured in tonnes aluminium; DUM_f is a dummy variable that is one in periods where the capacity utilization ratio is 0.97 or above and zero elsewhere; u_{if} and u_f are stochastic error terms with mean zero and no autocorrelation over time or across plants; The α's, β's and γ's are coefficients. The time trend, T, is assumed to proxy the level of technology. The capital measure, K_f, can be interpreted as an efficiency-corrected capital measure, cf. Sato (1975, pp. 6-7). This implies that the coefficient γ_{KT}, which is assumed to capture changes in capital efficiency over time, should equal zero.

We assume that plants are price-takers in variable input markets. Applying Shepard's Lemma to (3.1) gives the cost-share equation for each variable input, and the cost-share equation for input i includes the error term u_{if}. In Lindquist (1993), a multivariate error-correction model of the cost shares of labour and raw materials was estimated by full information maximum likelihood (FIML). That paper uses a panel of seven Norwegian plants in the primary aluminium industry for the period 1972-1990 and one plant that closed in 1981.[6] The regressions started in 1974 because of the dynamic specification. Because the cost shares must sum to unity by definition, the cost-share equation for electricity is obtained by using the adding up condition and the estimated cost share equations for the other variable inputs.

The estimated long-run coefficients in the cost-share equations from Lindquist (1993), that is α_{if}, β_{ij}, γ_{iX}, γ_{iK} and γ_{iT}, are used as a priori restrictions when estimating the static cost function in equation (3.1).[7] This two step procedure applied when estimating the cost function implies that the "equilibrium errors" (u_{ift}) from the first step, i.e. the estimation of the cost share equations, should be taken into account in the second step when the remaining coefficients in the cost function are estimated.[8] Estimating the

[6] We use primarily data from the manufacturing statistics data base at Statistics Norway. The manufacturing statistics employ the International Standard Industrial Classification (ISIC) and give annual data for plants classified at the 5-digit level of the ISIC. For a detailed presentation of the data see Lindquist (1993).

[7] All variables except the cost shares were normalized to one in 1972 when estimating the cost-share equations. This was necessary to obtain convergence of the general dynamic model. This normalization implies that the α_{if}'s could be set equal to the plant specific cost shares in 1972.

[8] The equilibrium errors (u_{ift}) are not equal to the residuals of the dynamic cost-share equations, that is the multivariate error-correction model. We calculate the equilibrium errors as the actual cost shares minus predicted cost-shares on the basis of the static or long-run

general cost function with all these restrictions and the u_{ift}'s as predetermined variables give a standard error of regression of 20 per cent. If we replace the equilibrium errors by constant coefficients to be estimated, that is $\eta_{if}=u_{ift}$, the standard error decreases to 7 per cent. This increases the number of independent coefficients to be estimated by 16 and adds flexibility to the cost function. The adding up condition requires that $\Sigma_i\eta_{if}=0$. This approach is equivalent to estimate the α_{if}'s without restrictions from step one but given the condition that $\Sigma_i\alpha_{if}=1$. Both Akaike's information criterion, the dominance ordering criterion and the likelihood dominance ordering criterion, cf. Akaike (1974) and Pollack and Wales (1991), prefer the more flexible cost function to that with the predetermined equilibrium errors included.

The key findings of Lindquist (1993) are: The conditional cost-share equations are homogeneous of degree zero in input prices ($\Sigma_j\beta_{ij}=0$), and the cross-price effects are symmetric ($\beta_{ij}=\beta_{ji}$). The hypothesis of Hicks-neutral technical progress is accepted ($\gamma_{iT}=0$), as is the hypothesis that the production technology is homothetic ($\gamma_{iX}=0$). The input coefficient for electricity is independent of the level of capacity ($\gamma_{EK}=0$; $\gamma_{MK}=-\gamma_{LK}$). In addition, the demand for variable inputs is inelastic and all own-price elasticities are above minus one. The mean industry elasticities show that all variable inputs are substitutes, but the cross-price elasticities between electricity and raw materials are approximately zero.

The preferred cost function is shown in table 3.1. We use the same panel as was used to estimate the cost-share equations in our earlier paper, but in this paper we do not normalize the variables. Table 3.1 includes the industry average cost shares in 1972, $\alpha_{i,1972}$, rather than all the plant specific cost shares. The small sample adjusted χ^2-form of the likelihood ratio test is applied in a general to specific search.[9]

In addition to the conclusions drawn from the estimated cost-share equations, the cost function in table 3.1 implies increasing returns to scale with respect to variable inputs. If variable inputs increase by one per cent, output increases by 1.3 per cent.[10] The

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relationships. The adding up condition requires that $\Sigma_i u_{ift}=0$.

[9] $\chi^2(j) = -2(T-k_1-1+j/2)/T \cdot[\ln L_0 - \ln L_1]$, where T denotes the number of observations, k_1 is the number of estimated coefficients in the general hypothesis, j is the number of restrictions, and $\ln L_0$ and $\ln L_1$ are the values of the log-likelihood function under the null and the general hypothesis, respectively, cf. Mizon (1977).

[10] This is somewhat above Klette (1994), who finds an elasticity of scale equal to 1.013 for Metals using Norwegian plant level panel data. This aggregate industry includes ferro alloys and other primary metals in addition to primary aluminium.

elasticity of scale equals the inverse elasticity of costs with respect to output, which is 0.76.

Table 3.1. The estimated cost function					
Coefficient	Estimate	Coefficient	Estimate	Restrictions from the cost-share equations and industry average cost shares in 1972	
γ_{01}	3.454 (.624)	η_{L1}	-0.131 (.108)	$\alpha_{L,1972}$	0.220
γ_{02}	5.225 (.573)	η_{L2}	-0.606 (.090)	$\alpha_{M,1972}$	0.598
γ_{03}	4.176 (.906)	η_{L3}	-0.280 (.154)	$\alpha_{E,1972}$	0.182
γ_{04}	4.512 (.682)	η_{L4}	-0.307 (.111)	β_{LL}	0.050
γ_{05}	5.087 (.669)	η_{L5}	-0.422 (.099)	β_{LM}	-0.050
γ_{06}	4.842 (.646)	η_{L6}	-0.390 (.132)	β_{LE}	0
γ_{07}	2.822 (.729)	η_{L7}	-0.125 (.175)	β_{MM}	0.140
γ_{08}	7.309 (2.16)	η_{L8}	-0.798 (.460)	β_{ME}	-0.090
γ_X	0.760 (.043)	η_{M1}	0.362 (.133)	β_{EE}	0.090
γ_{XX}	0 *	η_{M2}	0.724 (.131)	γ_{LX}	0
γ_K	*1)	η_{M3}	0.455 (.194)	γ_{MX}	0
γ_{KK}	0 *	η_{M4}	0.540 (.100)	γ_{EX}	0
γ_{XK}	0 *	η_{M5}	0.716 (.127)	γ_{LK}	-0.178
γ_T	0.106 (.017)	η_{M6}	0.618 (.165)	γ_{MK}	0.178
γ_{TT}	0 *	η_{M7}	0.142 (.131)	γ_{EK}	0
γ_{XT}	0 *	η_{M8}	1.378 (.425)	γ_{LT}	0
γ_{KT}	0 *			γ_{MT}	0
γ_{CAP}	0 *			γ_{ET}	0
lnL = -1492.73		R^2 = 0.993		DW = 1.675	
DF = 101		SER = 0.072		$\chi^2(8)$ = 9.902 (27%)	

Standard errors in parentheses. lnL is the value of the log-likelihood function. DF represents the degrees of freedom. The multiple correlation coefficient (R^2), the standard error (SER) and the Durbin-Watson statistic (DW) are reported. The small sample-adjusted χ^2(j)-statistic that tests the accepted cost function against the general is reported (cf. Mizon (1977)), j denotes the number of restrictions, and the significance level where the null hypothesis is rejected is given in parentheses.

1) $\gamma_K=-\gamma_{LK}\ln(Q_{Lft}/Q_{Mft})$, which implies that $\partial\ln C_{ft}/\partial\ln K_{ft}=0$.

* Restrictions supported by the likelihood ratio test at the five per cent significance level.

Full scale production is most cost efficient according to our results, and may explain why plants prefer to adjust sales by adjusting stocks rather than output.[11] Output variations may reflect necessary maintenance work on pot lines, and when market power

[11] This is based on discussions with representatives from the industry.

is present, that the profit maximizing strategy involves output reductions rather than just stock adjustments. The market may react differently to stock and output adjustments, because of the more temporary character of the first. Output reductions imply that output is permanently "lost".

The hypothesis of constant returns to scale up to the capacity constraint; $\gamma_X=1$, $\gamma_{XX}=\gamma_{XK}=\gamma_{XT}=0$, is clearly rejected by the likelihood ratio test. The test of this hypothesis against the general model yields a χ^2 statistic equal to 13.550, and the null (constant returns to scale) hypothesis is rejected at a significance level close to zero.[12] The hypothesis that the marginal cost curve is very steep close to the capacity constraint is also rejected, and γ_{CAP} is zero in the preferred cost function. This conclusion is robust to alternative definitions of a "high capacity utilization ratio", that is, to limits above or below 0.97. Our data on capacity includes the additional capacity that can be obtained from the upgrading of second grade aluminium in addition to own-smelting capacity. Such upgrading was important for some plants during the late eighties, when the utilization ratio of own-smelting capacity was very high in many plants. This possibility suggests that at least some plants do not face an absolute short-run capacity constraint equal to the smelting capacity, and may explain why a vertical segment of the marginal cost curve is not found.

The cost function in table 3.1 includes two effects of investments in increased capacity on variable costs: First, variable costs decrease due to a substitution of labour for raw materials. This may be interpreted as a capital embodied technical change effect. And second, variable costs increase because of complementarity between capital and variable inputs. By restriction, the two effects cancel. When testing the restriction that the elasticity of costs with respect to capacity is zero against the general cost function, we get $\chi^2(1)=2.433$. We must accept a 12 per cent probability of rejecting a true null hypothesis to reject that $\partial \ln C_{ft}/\partial \ln K_{ft}=0$, that is to reject the restriction $\gamma_K = -[\gamma_{KK}\ln K_{ft} + \gamma_{XK}\ln X_{ft} + \gamma_{KT}\ln T_t + \gamma_{LK}\ln(Q_{Lft}/Q_{Mft})]$. The 12 per cent significance level is also required to reject the zero capacity effect restriction on the preferred cost function.

There is a trade off between scale and capacity effects on variable costs in our data. When estimating the general cost function with no restrictions on these effects, we find the elasticity of costs with respect to output and capacity to be around 0.4 and 1.2 respectively. An increase in variable costs by 1.2 per cent when capacity increases by one per cent and output remains constant is unreasonably high. Our output and capacity

[12] This implies that using average variable costs as a proxy for marginal cost, as in Klette (1990), involves a measurement error.

variables are strongly correlated, and we may face an identification problem with respect to the output and capacity elasticities.

The preferred cost function includes a positive trend coefficient. One interpretation of the positive trend effect is that an increase in processing and specialization have shifted the average variable cost curve upwards over time. An alternative explanation is that the trend coefficient reflects a misspecification problem because of our choice of functional form or missing dynamics. The trend effect diminishes over time; while the annual trend effect on variable costs is 2.2 per cent on average over 1974-1990, the effect is 0.6 per cent in 1990. A zero restriction on the trend coefficient γ_T is clearly rejected, but we still find support for increasing returns to scale with respect to variable inputs. The coefficient γ_X increases from 0.76 to 0.87, however.

To be well behaved, the cost function must be non-decreasing and concave in prices of variable inputs and non-increasing and convex in capital, cf. Brown and Christensen (1981, p. 217-218). Lindquist (1993) concludes that most sample points support the "concave in prices" condition. The own-price elasticity of electricity is positive in a couple of years for plants 2 and 8, however, when the cost share of electricity is very low. Plant 8 was closed down in 1981. The mean industry own-price elasticities are negative in all years. The "non-decreasing in prices" condition is also satisfied in most sample points. The main exception is plant 8. We also face a problem with the labour cost elasticity of plant 2, which is around -0.05. The requirements with respect to capital are satisfied in all sample points by restriction. Appendix 2 shows actual variable costs and fitted variable costs obtained from the cost function in table 3.1. Our conclusion is that the preferred cost function predicts the development of variable costs well.

4. Price-cost margins and competition

The marginal cost that is implied by the accepted cost function are used with plant-specific prices to calculate the price-cost margins: $\mathcal{L}_{ft} = [P_{ft} - \partial C_{ft}(.)/\partial X_{ft}]/P_{ft}$. These margins, which are presented in figure 4.1, are clearly not constant over time. One plant exhibits periods with negative price-cost margins, which is not consistent with the simple single-period profit maximization models discussed in section 2. However, a plant that maximizes the discounted flow of expected profits under uncertainty and when mistakes are costly should use discounted marginal cost rather than current marginal cost as the decision variable, cf. Phlips (1980) and Blinder (1982). In this case, and when long-term contracts are made, responses to current demand or cost shocks will be somewhat sticky, and negative margins may prevail. Even with full certainty, negative margins may well be part of an optimal strategy if regaining market shares involves costs. In their annual reports, the Norwegian aluminium companies Hydro and Elkem stress the importance of customer service to gain and keep market shares, which suggests that regaining market shares does involve costs in this industry.

Figure 4.1. Plant specific price-cost margins

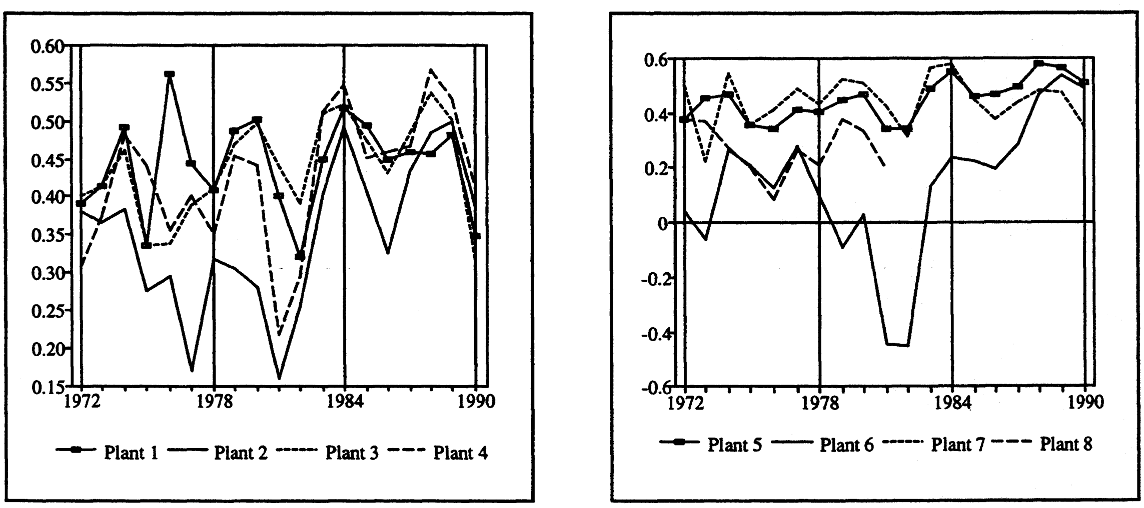


Table 4.1 gives the mean, maximum and minimum values, and the standard deviation, of the price-cost margin of each plant. The margins are significantly above zero in most sample points, the only exception is plant 6.[13] The industry margin is significantly

[13] Average variable costs and prices are treated as deterministic variables when calculating the standard error of the price-cost margins. The estimated marginal cost curves are used; $var(\mathcal{L}_{ft})=[C_{ft}/(X_{ft}\cdot P_{ft})]^2\cdot var(\gamma_X)$, and the standard error is found by taking the square root of this expression.

above zero in all years. The simple competitive model with price equal to marginal cost is rejected, as was expected because of increasing returns to scale.

Table 4.1. Price-cost margins ($\mathcal{L}_f$)

	Mean[1]	Maximum[1]	Minimum[1]	St.dev.	Correl($\mathcal{L}_f^{DT}$,IPDT)[2]	Dickey-Fuller test[3]
Plant 1	0.44 (.02)	0.56 (.01)	0.32 (.02)	0.06	0.20	-4.69 (s)
Plant 2	0.35 (.02)	0.50 (.02)	0.16 (.03)	0.10	0.30	-2.01
Plant 3	0.44 (.02)	0.54 (.01)	0.31 (.02)	0.07	0.12	-2.31
Plant 4	0.42 (.02)	0.57 (.01)	0.22 (.02)	0.09	0.13	-2.76
Plant 5	0.45 (.02)	0.58 (.01)	0.34 (.02)	0.07	0.52	-1.93
Plant 6	0.13 (.03)	0.54 (.01)	-0.45 (.04)	0.27	0.32	-1.60
Plant 7	0.44 (.02)	0.57 (.01)	0.22 (.02)	0.09	-0.03	-5.73 (s)
Plant 8	0.27 (.02)	0.38 (.02)	0.19 (.03)	0.10	0.59	-2.39
Industry average[4]	0.38 (.02)	0.52 (.01)	0.19 (.02)	0.09	0.25	-4.79 (s)[5]

1) In parentheses: The standard error of the price-cost margin. The standard error of the mean margin is the mean of the standard error in each sample point.
2) Correlation between detrended price-cost margins ($\mathcal{L}_f^{DT}$) and cycles in demand proxied by the detrended industry production in OECD (IPDT). The trend effect, which is found by regressing each variable on a linear trend variable, is subtracted from the variables.
3) (s) implies a significant Dickey-Fuller test at the five per cent significance level and that non-stationary margins is rejected. The critical value of the Dickey-Fuller test is -3.05 for plants 1-7 and -3.33 for plant 8.
4) The industry average is calculated as the weighted sum of the price-cost margins of Norwegian plants. We use plant outputs as weights.
5) The panel data rather than the industry average data is used. The critical value is -2.88.

The mean margin is above 0.4 for most plants.[14] The somewhat lower price-cost margins of plants 2 and 8 are largely due to a cost disadvantage, that is a high marginal cost due to a high average variable cost. These plants are relatively small. In addition, plant 2 has obtained a low average price. The very low price-cost margin of plant 6, which is one of the largest aluminium plants in our sample, is due to a low average

[14] Using Norwegian plant level panel data over the period 1980-1990, Klette (1994) finds a price-cost margin equal to 0.1 for Metals. This aggregate industry includes ferro alloys and other primary metals in addition to primary aluminium.

price.[15] Plant 6's margin increased markedly during the late eighties as a result of an increase in price.

In an attempt to reveal the importance of economies of scale, we compare price-cost margins based on marginal cost with price-cost margins based on average variable costs. The industry margin defined over average variable costs equals 0.27, which is 29 per cent below the industry margin based on marginal cost. Hence, economies of scale seem to be a significant source of positive price-cost margins in this industry.

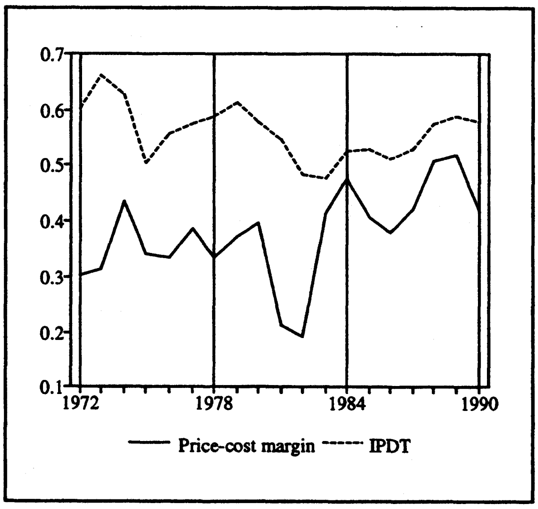
We now discuss three explanations to the cyclical behaviour of price-cost margins that is illustrated in figure 4.1. First, equations (2.6) and (2.7) show that non-constant margins may imply oligopolistic behaviour and reflect variation in the perceived competitive reactions of other plants or entry and exit of competitors. Internationally, industry concentration has declined, and one may expect price-cost margins to follow a negative trend as new and possibly more efficient plants enter the market and put a downward pressure on the price. Increased output by Norwegian plants have the opposite effect on the margins because of the presence of economies of scale, however. Second, price elasticities may depend on the deviation of demand from its trend path rather than being constants. In this case we expect stationary fluctuations in the margins, cf. Rotemberg and Woodford (1991, p. 75). If own-price elasticities decrease in periods with expanding demand and increase in periods with contracting demand relative to the trend path, price elasticities will be countercyclical and generate procyclical price-cost margins. And third, procyclical price-cost margins may be due to rigidities in supply because of capacity limits and the lumpiness of investments characteristic of this industry. Stock adjustments and upgrading of second grade aluminium reduce this rigidity, however.

Table 4.1 reports the correlation of detrended price-cost margins and the detrended industrial production in OECD, which is assumed to reflect deviation in demand from its trend path. With the exception of plant 7, support is found for a procyclical price-cost margin. The industry margin is clearly procyclical, and the average value in peak and

[15] The mean price-cost margin based on average variable costs rather than estimated marginal cost is -0.13 for plant 6. This suggests that vertical integration with a neighbouring rolling mill in the same concern is important for this plant. Plant 6 delivers primary aluminium in liquid form to the rolling mill. The price of liquid aluminium is below the price of aluminium in ingot, but the negative price-average variable costs margin suggests that the price information for this plant in the manufacturing statistics is misguiding. We assume that vertical integration does not affect the input demand behaviour or cost structure of this plant, but an analysis of price determination may be affected.

trough periods are 0.39 and 0.35 respectively.[16] Because price-cost margins are found to be significantly above zero in most sample points, cf. table 4.1, we conclude that market power is present in both trough and peak periods.

Figure 4.2. Average price-cost margin of the Norwegian primary aluminium industry and detrended industry production in OECD (IPDT)



If the variation in price-cost margins over time is primarily due to rigidities on the supply side, unexpected demand or supply side shocks or cyclical price elasticities, we expect the margins to be stationary and fluctuate around a constant level. The Dickey-Fuller test (with a constant term) is applied to test the hypothesis that the price-cost margins are integrated of order one, that is non-stationary, against the alternative hypothesis that the margins are integrated of order zero, i.e. stationary, cf. Dickey and Fuller (1979) and Engle and Yoo (1987). We use the formula in MacKinnon (1991) to calculate the critical values consistent with our sample size. A significant Dickey-Fuller test supports the hypothesis that the margins are stationary. The results from this test are reported in the last column of table 4.1. At the five per cent significance level, non-stationarity is rejected for two plants only. Figure 4.1 shows that there is a small tendency to increasing margins over time for the other plants. Applying the Dickey-Fuller test to the entire panel increases the power of the test, and in this case the null hypothesis of non-stationarity is clearly rejected, however.

[16] This is consistent with Domowitz et al. (1986), who find procyclical margins in concentrated industries. Chirinko and Fazzari (1994), who analyse a panel of firm-level data, conclude that "when market power varies temporally, it is usually procyclical". On the other hand, analyses of US data at both the aggregate and relatively disaggregate industry level have found countercyclical markups and hence also price-cost margins, cf. Bils (1987) and Rotemberg and Woodford (1991). This is true with respect to the Primary metals industry as well, as is reported by Rotemberg et al.

Since the price-cost margins seem to fluctuate around constant levels or a small positive trend, we conclude that an increase in the degree of competition internationally due to entry has not put a downward pressure on the mean margins of Norwegian plants. This does not rule out that a negative pressure may be present in trough periods, if this is offset by a higher margin in peak periods due to large demand shocks. Bresnahan and Suslow (1989), who analyse the aluminium industry in North America, find that the decline in concentration has affected the industry's pricing behaviour and reduced the price-cost margin over the cyclical trough. They also conclude that oligopoly power is nonessential to price determination in peak periods, because capacity constraints result in right-angled marginal cost curves and imply that price is determined by the intersection of the demand curve and the industry smelting capacity in peak periods.

We test the hypothesis that the decline in industry concentration internationally has put a downward pressure on price and hence on price-cost margins in trough periods. As a measure of concentration, we use the share of world smelting capacity accounted for by the six historically large aluminium companies (CONS).[17] To discriminate between trough (T) and peak (P) periods, we use the detrended measure of industrial production in OECD. When this detrended activity measure is below its average, the period is defined as trough. The dummy variable DUMT equals one in trough periods and zero elsewhere. Auxiliary regressions are run in which the panel of price-cost margins is regressed on the concentration measure. TIME is a deterministic trend variable. The whole panel of margins is used; $\mathcal{L}=(\mathcal{L}_1, \mathcal{L}_2,.., \mathcal{L}_8)$, where $\mathcal{L}_f$ is the vector of observations of plant f. The 1972 and 1973 observations are included. DUM_f, f=1,..,8, are plant specific dummy variables. The standard errors are given in parentheses.

$$\begin{array}{llllll}
\mathcal{L}_t = & 0.450 & -\ 0.091\ DUM_2 & -\ 0.436\ DUM_6 & -\ 0.164\ DUM_8 & +\ 0.021\ DUM_6 \cdot TIME_t \\
 & (.015) & (.027) & (.057) & (.037) & (.005) \\
 & -\ 0.275\ DUMT_t & -\ 0.170\ DUM_6 \cdot DUMT_t & +\ 13.231\ (1/CONS_t) \cdot DUMT_t & & \\
 & (.105) & (.055) & (5.50) & &
\end{array}$$

According to this simple regression, the decline in industry concentration has a significant positive effect on price-cost margins in trough periods. That is, we do not find support for the conclusion in Bresnahan and Suslow (1989) that the decline in industry concentration has put downward pressure on the price and hence on price-cost margins in trough periods. Given their assumption of constant marginal cost up to the capacity constraint, Bresnahan and Suslow use unit labour and material costs when

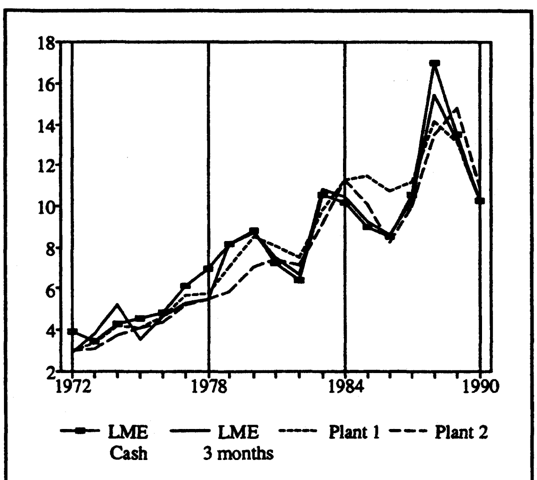
[17] Data for 1971 and 1979 are from Bresnahan and Suslow (1989, p. 280), and data for 1980 and 1985-1990 are provided to us by Hydro Aluminium. Data for the remaining years are calculated by assuming that this concentration measure follows a linear trend.

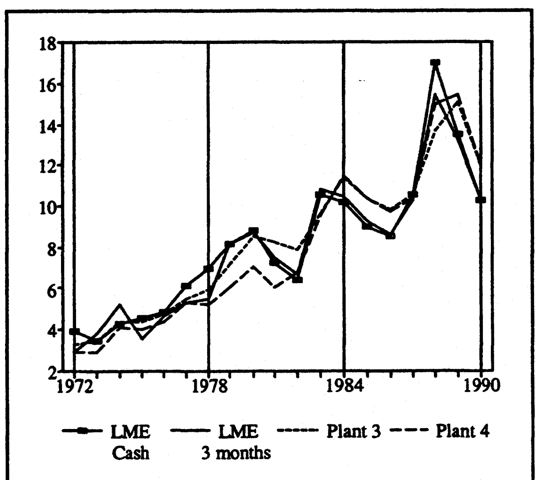
calculating the industry price-cost margin, however. Our conclusion is robust to the choice of cost measure, that is to whether we use average variable costs rather than the estimated measure of marginal cost when calculating the price-cost margins. This conclusion also goes through if we use detrended price-cost margins.

To discriminate between the differentiated products and the homogeneous goods case, we test the hypothesis that Norwegian aluminium prices equal the spot market price in the "long-run". Norwegian plants make extensive use of long-term contracts, which may involve fixed prices or prices linked to those registered at the LME. This implies that short-run price differences may well exist for physically identical aluminium products, cf. the introductory section. Figure 4.3 shows the development in Norwegian prices and the cash and 3-month price of primary aluminium registered at the London Metal Exchange (LME).[18] All prices are measured in Norwegian kroner (NOK).

Figure 4.3 reveals important price variation both across Norwegian plants and between Norwegian prices and the spot market prices. The cash and 3-month LME-price of 99.7 per cent primary aluminium ingot differ only marginally, after 1979. With the exception of plant 6, Norwegian prices seem to vary around the LME-prices and to follow the same trend.

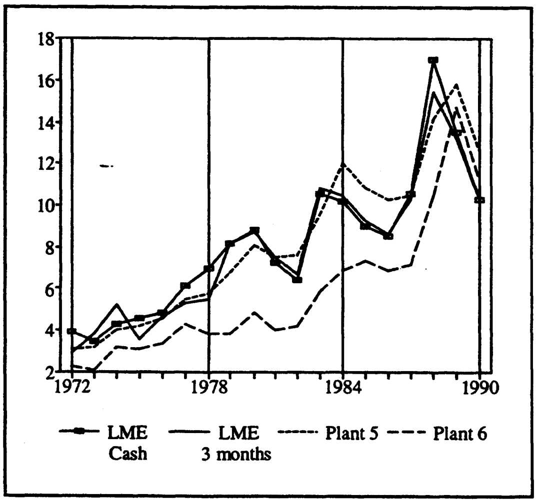
Figure 4.3. The cash and 3-month price of primary aluminium registered at the London Metal Exchange and the aluminium prices reported by Norwegian plants, NOK

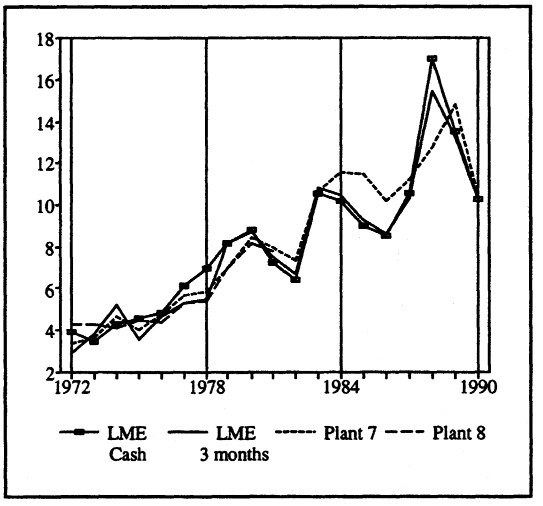




[18] The cash spot market price is taken from World Metal Statistics. Primary aluminium was not traded at the LME before 1978, and the cash price is available on an annual basis from 1979. The Canadian price of primary aluminium exported to the UK is used as a proxy of the world market price before 1979. This price is reported by the International Monetary Found (IMF). The 3-month price was provided to us by Hydro Aluminium.

Figure 4.3. continues





The "long-run price equalization" hypothesis is tested econometrically. For each Norwegian price (P_f), we estimate an error-correction model that includes the 3-month LME-price (PW), a constant term and a trend variable. Because the cash and 3-month LME-price are very similar, we choose to concentrate on the latter. Since primary aluminium was not traded at the LME before 1979, which may create an inconsistency problem in the world market price before and after this year, we also include a dummy variable in the general model. The dummy variable (DUM79), equals zero up to 1979 and one since. The general model includes two lags of the spot market price and one lag of the own-price. The results are reported in table 4.2. Lower case letters indicate that the variables are in logarithms, and $\Delta v_t = \log(V_t/V_{t-1})$, that is the first difference of the logarithm of a variable. The restrictions of long-run price homogeneity and price equalization are tested. The F-form of the Lagrange multiplier test has been applied to test for first-order autocorrelation in the residuals (AR(1)), cf. Kiviet (1986). To test for cointegration between the variables in the long-run relationship, we use the test suggested in Kremers et al. (1992), that is based on the t-ratio of the error-correction coefficient (t_{ECM}). A significant test implies that the null hypothesis of no cointegration is rejected. The critical values of the Dickey-Fuller test are used, cf. MacKinnon (1991).

We do not reject the hypothesis of long-run price homogeneity for any plant. A one per cent increase in the LME-price yields a one per cent increase in Norwegian aluminium prices in the long-run. In addition, we find support for long-run price equalization for plants 2, 4, 6 and 8. All Norwegian prices show significant short-run discrepancies from the LME-price, however. The first year effect on own-price of a one per cent increase in the LME-price is around 0.5-0.6 per cent for most plants. The cumulative effect at t+1, shown by the standardized interim multiplicator, is as much as 0.8-1.0 per cent for most plants, which implies rapid adjustment. These results suggest that much of the observed price differences are due to long-term contracts with varying terms made by Norwegian plants. Variation in quality, in addition to products tailor-made to fit particular customers, customer service and reliability of delivery, may provide a basis for a short-run and, for some plants, a permanent price above the LME-prices. Price homogeneity is assumed to reflect that products are close substitutes, however. The relatively slow adjustment for plant 6 may reflect a missing negative constant. If included, the constant is not significant, however. The t_{ECM}-test supports the hypothesis of cointegration for all the long-run relationships reported in table 4.2.

Table 4.2. Testing the hypothesis that Norwegian prices of primary aluminium equals the 3-month LME-price in the long-run. The left-hand side variable is Δp_{ft}

Variable	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
$\Delta p_{f,t-1}$	0 *	0 *	0 *	0 *	0 *	0 *	0 *	0 *
Δpw_t	0.56	0.50	0.52	0.61	0.48	0.44	0.65	0.51
	(0.07)	(0.08)	(0.04)	(0.09)	(0.06)	(0.15)	(0.08)	(0.08)
Δpw_{t-1}	0 *	0 *	0 *	0 *	0 *	0 *	0 *	0 *
$(p_f - pw)_{t-1}$	-0.48	-0.72	-0.73	-0.53	-0.63	-0.23	-0.71	-1.00*
	(0.13)	(0.12)	(0.08)	(0.14)	(0.11)	(0.09)	(0.17)	
Constant	0.04	0 *	0.06	0 *	0.06	0 *	0.05	0 *
	(0.02)		(0.01)		(0.01)		(0.02)	
Trend	0 *	0 *	0 *	0 *	0 *	0 *	0 *	0 *
DUM79	0 *	0 *	0 *	0 *	0 *	0 *	0 *	0 *
SIM_{t+1}	0.83	0.86	0.90	0.93	0.78	0.54	1.11	1.02
SER	0.063	0.079	0.035	0.089	0.059	0.154	0.075	0.056
DW	1.18	1.48	1.64	1.47	1.62	1.85	1.90	1.37
AR(1)	1.82	1.33	0.25	1.51	0.80	0.04	0.35	2.80
t_{ECM}	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)
Restr. p	-0.69	0.09	-0.06	1.12	1.39	-0.73	-0.15	0.09
Restr. c		-0.02		0.98		-1.13		0.23

The estimation period is 1974 to 1990, except for plant 8 for which the estimation ends in 1981. Standard errors are in parentheses. SIM_{t+1} is the cumulated interim multiplier at t+1. The standard error of the regression (SER), the Durbin-Watson statistic (DW), and the t-statistic that tests the restriction of long-run price homogeneity (Restr. p) and a zero constant term (Restr. c) are reported. The critical value of the t_{ECM}-test is -1.96 for plants 1,3,5 and 7, and -1.96 for plants 2,4 and 6, and -1.99 for plant 8. The t_{ECM}-test for plant 8 is based on the freely estimated coefficient of $(p_f\text{-}pw)_{t-1}$, which equals -1.05 (0.19).
* Restriction supported by the data. (s) Significant at the five per cent significance level.
When estimated freely, the coefficient of $(p_f\text{-}pw)_{t-1}$ equals -1.05 (0.19). The t_{ECM}-test is based on this.

The estimated constant terms in table 4.2 imply that some Norwegian prices are as much as 7-8 1/5 per cent above the 3-month LME-price. Hence, product differentiation seems to be important for some plants. The relatively high price-cost margins of plants 1, 3, 5 and 7, are partly due to high prices.

4. Final remarks

This paper measures the degree of market power in the Norwegian primary aluminium industry from data on prices and estimated variable cost equations. The key findings are:

1. Norwegian aluminium plants charge a procyclical price-cost margin that is significantly above zero in both trough and peak periods. The simple competitive hypothesis is rejected.

2. The estimated variable cost function implies increasing returns to scale with respect to variable inputs. Economies of scale are important for explaining the observed margins.

3. The price-cost margins seem to fluctuate around constant levels or a small positive trend, and the decline in industry concentration internationally has not put a downward pressure on the margins.

4. The deviation of Norwegian aluminium prices from the spot market price can to a large degree be explained by the use of long-term contracts made by Norwegian plants. Price homogeneity is found, and a one per cent increase in the spot market price increases Norwegian prices by one per cent in the long-run. The hypothesis of differentiated products is not rejected, since several plants are found to charge a price permanently over the spot market price. Price homogeneity is assumed to reflect that the products are close substitutes, and for a chosen product or quality, the price is determined by the spot market price and a sustainable markup on the spot market price.

Appendix 1.

The correspondence between the differentiated products model and the homogeneous goods model.

The first-order profit maximizing condition of plant f, f=1,..,m, in the differentiated products case is given in equation (A.1), which corresponds to equation (2.3).

$$\text{(A.1)}\quad P_f \{1 + (\partial P_f/\partial X_f)\cdot(X_f/P_f) + \Sigma_{j\neq f}[(\partial P_f/\partial X_j)\cdot(X_j/P_f) \cdot (\partial X_j/\partial X_f)\cdot(X_f/X_j)]\} = \partial C_f(.)/\partial X_f$$

The variables are defined in section 2. $\varepsilon_f = -(\partial P_f/\partial X_f)\cdot(X_f/P_f)$ is the inverse own-price elasticity of demand faced by plant f; $\mu_{fj} = -(\partial P_f/\partial X_j)\cdot(X_j/P_f)$ is the inverse cross-price elasticity of demand between product f and j; $\theta^D_{fj} = (\partial X_j/\partial X_f)\cdot(X_f/X_j)$ is plant f's conjectural variation elasticity with respect to plant j; f,j=1,..,m.

In the homogeneous goods case, all plants face the same demand curve and price: $P_1 =..= P_f =..= P_m \equiv P$ and $\partial P_f/\partial X_j \equiv \partial P/\partial X$, $\partial P_f/\partial P^* \equiv \partial P/\partial P^*$, $\partial P_f/\partial M \equiv \partial P/\partial M$ for f,j=1,..m, where $X = \Sigma_f X_f$. We implement these restrictions in (A.1), which give

$$P \{1 + (\partial P/\partial X)\cdot(X_f/P) + \Sigma_{j\neq f}[(\partial P/\partial X)\cdot(X_j/P) \cdot (\partial X_j/\partial X_f)\cdot(X_f/X_j)]\} = \partial C_f(.)/\partial X_f$$

$\Rightarrow$

$$P \{1 + (\partial P/\partial X)\cdot(X/P)\cdot [X_f/X \cdot (1 + \Sigma_{j\neq f}\partial X_j/\partial X_f)]\} = \partial C_f(.)/\partial X_f$$

In addition we have

$$1 + \Sigma_{j\neq f}\partial X_j/\partial X_f = 1 + \partial(X - X_f)/\partial X_f = 1 + \partial X/\partial X_f - \partial X_f/\partial X_f = \partial X/\partial X_f$$

$\Rightarrow$

$$P \{1 + (\partial P/\partial X)\cdot(X/P) \cdot (\partial X/\partial X_f)\cdot(X_f/X)\} = \partial C_f(.)/\partial X_f$$

or alternatively

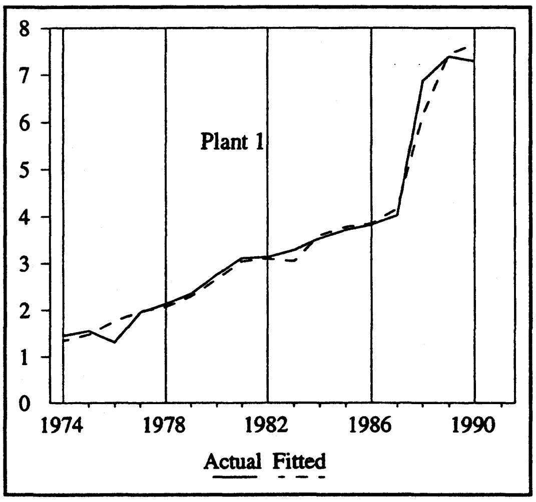
$$\text{(A.2)}\quad P [1 - \varepsilon\cdot \theta^H_f] = \partial C_f(.)/\partial X_f$$

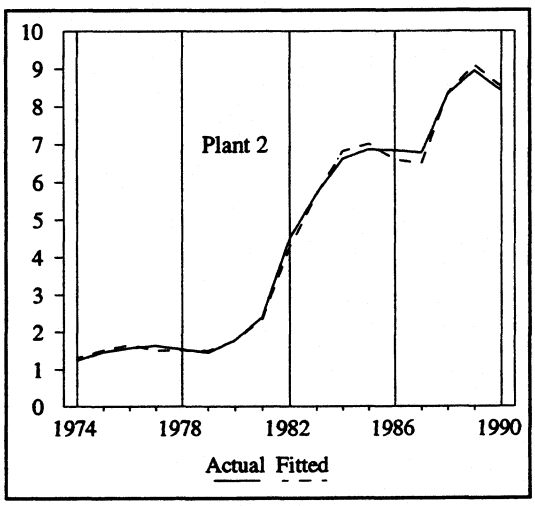
where $\varepsilon = -(\partial P/\partial X)\cdot(X/P)$ is the inverse demand elasticity; $\theta^H_f = (\partial X/\partial X_f)\cdot(X_f/X)$ is plant f's conjectural variation elasticity with respect to total supply inclusive f's own output. Equation (A.2) is identical to equation (2.5).

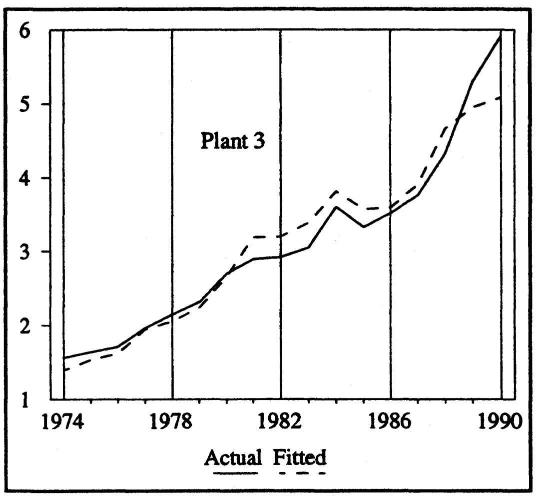
Appendix 2.

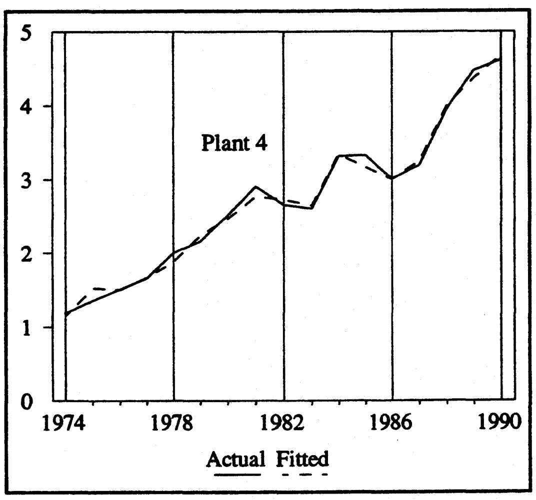
Actual and fitted variable costs, 1972=1 to make the plants anonymous.

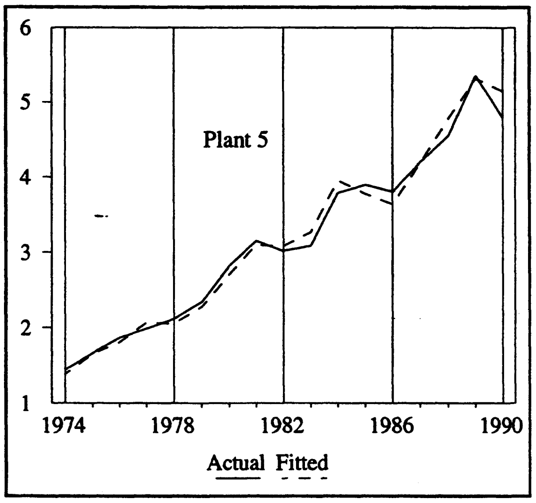
The preferred cost function in table 3.1 is used.

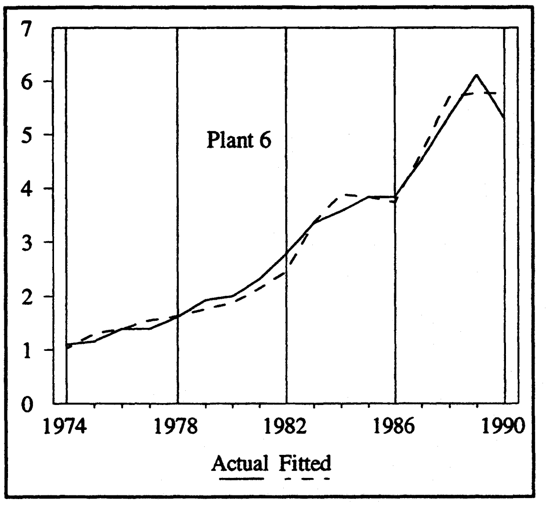


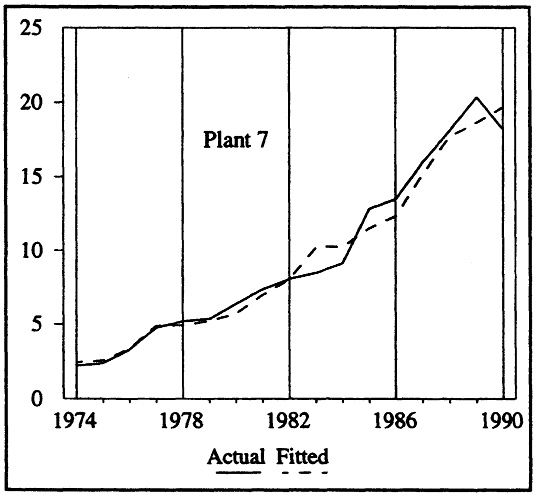


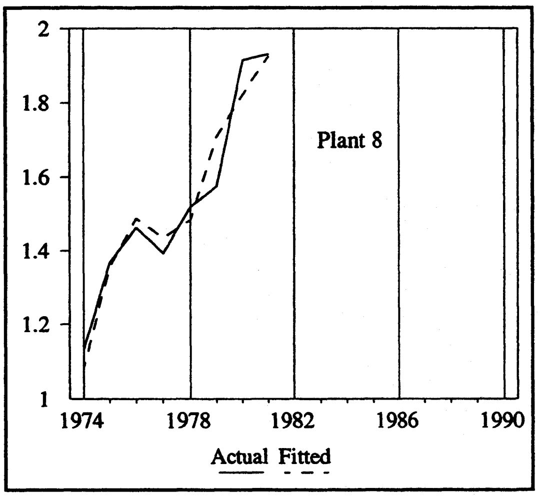





Plant 5
Actual Fitted


Plant 6
Actual Fitted


Plant 7
Actual Fitted


Plant 8
Actual Fitted

References

Akaike, H. (1974): "A New Look at the Statistical Model Identification". *IEEE Transactions on Automatic Control 19*, 716-723.

Appelbaum, E. (1979): "Testing Price Taking Behaviour", *Journal of Econometrics 9*, 283-294.

Appelbaum, E. (1982): "The Estimation of the Degree of Oligopoly Power", *Journal of Econometrics 19*, 287-299.

Bils, M. (1987): "The cyclical behavior of marginal cost and price", *American Economic Review 77*, 838-857.

Blinder, A. (1982): "Inventories and sticky prices: more on the microfoundations of macroeconomics", *American Economic Review 72*, 334-348.

Bresnahan, T.F. (1989): "Empirical Studies of Industries with Market Power", in R. Schmalensee and R.D. Willig (eds.), *Handbook of Industrial Organization, Volume II*, Amsterdam: North-Holland, 1011-1057.

Bresnahan, T.F. and V.Y. Suslow (1989): "Oligopoly Pricing with Capacity Constraints", *Annales d'Économie et de Statistique 15/16*, 267-289.

Brown, R.S. and L.R. Christensen (1981): "Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application to U.S. Agriculture, 1947 to 1974", in E.R. Berndt and B.C. Field (eds.), *Modelling and Measuring Natural Resource Substitution*, Cambridge, Mass.: MIT Press, 209-229.

Chirinko, R.S. and S.M. Fazzari (1994): "Economic Fluctuations, Market Power, and Returns to Scale: Evidence from Firm-level Data", *Journal of Applied Econometrics 9*, 47-69.

Christensen, L.R., D.W. Jorgenson and L. Lau (1971): "Conjugate Duality and the Transcendental Logarithmic Production Function", *Econometrica 39*, 255-256.

Christensen, L.R., D.W. Jorgenson and L. Lau (1979): "Transcendental Logarithmic Production Frontiers", *Review of Economics and Statistics 55*, 28-45.

Dickey, D.A. and W.A. Fuller (1979): "Distribution of the estimators for autoregressive time series with a unit root", *Journal of the American Statistical Association* 84, 427-431.

Domowitz, I., R.G. Hubbard and B.C. Petersen (1986): "Business cycles and the relationship between concentration and price-cost margins", *Rand Journal of Economics 17*, 1-17.

Engle, R.F. and B.S. Yoo (1987): "Forecasting and Testing in Co-Integrated Systems", *Journal of Econometrics 35*, 143-159.

Friedman, J. (1983): *Oligopoly Theory*, Cambridge University Press.

Froeb, L. and J. Geweke (1987): "Long Run Competition in the U.S. Aluminum Industry", *International Journal of Industrial Organization 5*, 67-78.

Geroski, P.A. (1988): "In Pursuit of Monopoly Power: Recent Quantitative Work in Industrial Economics", *Journal of Applied Econometrics 3*, 107-123.

Kiviet, J.F. (1986): "On the rigour of some misspecification tests for modelling dynamic relationships", *Review of Economic Studies 53*, 241-261.

Klette, T.J. (1990): The Norwegian Aluminium Industry, Electricity Prices and Welfare, In Økonomiske Avhandlinger 6, The University of Oslo, Norway.

Klette, T.J. (1994): Estimating Price-Cost margins and Scale Economies from a Panel of Microdata, Discussion Paper No. 130, Statistics Norway, Oslo.

Kremers, J.J.M., N. Ericsson and J.J. Dolado (1992): "The Power of Cointegration Tests", *Oxford Bulletin of Economics and Statistics 54*, 325-348.

Lerner, A. (1934): "The concept of monopoly and the measurement of monopoly power", *Review of Economic Studies 11*, 157-175.

Lindquist, K.G. (1993): The Existence of Factor Substitution in the Primary Aluminium Industry: A Multivariate Error Correction Approach on Norwegian Panel Data, Discussion Paper No. 106, Statistics Norway, Oslo.

MacKinnon, J.G. (1991): "Critical Values for Cointegration Tests", in R.F. Engle and C.W.J. Granger (eds.), *Long-Run Economic Relationships. Readings in Cointegration.* Oxford University Press, 267-276.

Mizon, G. (1977): "Inferential Procedures in Nonlinear Models: An Application in a UK Industrial Cross Section Study of Factor Substitution and Returns to Scale". *Econometrica 45*, 1221-1242.

Phlips, L. (1980): "Intertemporal price discrimination and sticky prices", *Quarterly Journal of Economics 94*, 525-542.

Pollak, R.A. and T.J. Wales (1991): "The likelihood dominance criterion. A new approach to model selection". *Journal of Econometrics 47*, 227-242.

Reynolds, S.S. (1986): "Strategic Capital Investment in the American Aluminum Industry", *The Journal of Industrial Economics 34*, 225-245.

Rosenbaum, D.I. (1989): "An Empirical Test of the Effect of Excess Capacity in Price Setting, Capacity-Constrained Supergames", *International Journal of Industrial Organization 7*, 231-241.

Rotemberg, J.J. and M. Woodford (1991): "Markups and the Business Cycle", in *NBER Macroeconomics Annual 1991*, Cambridge, Mass.: MIT Press, 63-129.

Rønning, J.I., B. Svendsen and S. Utstumo (1986): *Økt videreforedling av aluminium i Norge, muligheter og begrensninger*, Rapport No.65, Industriøkonomisk Institutt, Bergen.

Sato, K. (1975): *Production Functions and Aggregation*, Contributions to economic analysis Vol. 90, Amsterdam: North-Holland.

Tirole, J. (1989): *The Theory of Industrial Organization*, Cambridge, Mass.: MIT Press.

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