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The Response by the Norwegian Aluminium Industry to Changing Market Structure

Abstract:
This paper analyses how changes in market structure have affected the margins (measured by the Lerner index) of Norwegian aluminium plants. Instead of showing the expected negative trend, due to increased competition internationally, the margins are found to move procyclically around a constant that significantly exceeds zero. Three explanations for this stability in the levels of the margins are identified; a better exploitation of scale economies, increased productivity and product specialisation which allows Norwegian producer prices to increase more rapidly than the international reference price.

Keywords: Lerner index, Translog cost function, Aluminium industry, Differentiated products

JEL classification: C23, D21, D43, L61

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1. Introduction

For several decades, the aluminium market has been affected by an increase in the degree of competition internationally, i.e. a decline in industry concentration. 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] In the early post-war oligopoly setting, prices were set to cover costs plus a margin (Rønning et al., 1986). Over time the industry has changed to be more competitive and less oligopolistic, cf. Reynolds (1986, p. 231) and Froeb and Geweke (1987), and fringe plants have had a significant impact on price determination since the mid-seventies. Today, the price of aluminium on the London Metal Exchange (LME), where aluminium has been traded since 1978, is of major importance to most trade in aluminium. It is common for producers and consumers to enter into long-term contracts specifying quantities, grades and shapes, while the price is related to the LME-price, often at the time of delivery.

It is generally assumed that this change in market structure has put a downward pressure on the margins in the aluminium industry. Margins are measured by the Lerner index (Lerner, 1934), i.e. as price minus marginal cost divided by price. The Norwegian aluminium industry, which export most of its production, has responded to the change in market structure in a number of ways. As a result of plant closures and mergers, the Norwegian aluminium industry has been dominated by two companies since the mid-eighties. These are Elkem Aluminium, which owns two aluminium plants, and Hydro Aluminium, which owns four plants and is a major share-holder in a fifth. This consolidation on the producer side has probably provided the basis for other important strategic actions; Over time, vertical integration both upstream and downstream have become increasingly important. The access to alumina, which is the major raw material in this industry, is secured by vertical integration and long-term agreements. And, Elkem, which is strategically related to Alcoa, delivers a substantial part of its production to Alcoa's manufacturing plants, while Hydro has built up an extensive semi-manufacturing system in Europe and North America. The aluminium is primarily sold using long-term contracts. Furthermore, reading their annual reports, it is clear that both companies have adopted strategies to specialise products and increase their productivity.

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

While some of the actions described above are likely to reduce production costs, others, such as the effort to specialise products, may help Norwegian plants to sell at a price above the LME-price, that is at a premium. To what degree these actions have neutralised the negative competition effect on the margins is an empirical issue, which we will try to resolve in this paper.

Earlier studies of the aluminium industry have in general assumed fixed input coefficients and constant returns to scale. (One exception is Reynolds (1986), who calibrates alternative variable cost functions for the U.S. aluminium industry.) As a consequence, the standard approach when calculating margins involves using a measure of average variable costs, see Froeb and Geweke (1987), Domowitz et al. (1987) and Rosenbaum (1989) who all analyse the U.S. aluminium industry using aggregate industry data, and Klette (1990) who uses plant-level panel data to analyse the Norwegian aluminium industry. With the exception of Klette (1990), it is also generally assumed that the aluminium industry produces a homogeneous product with a common price. If the constant returns to scale or homogeneous product assumptions are not valid, the standard way of calculating margins is not correct and may lead to invalid inference about the magnitude of the margins and their development over time.

In this analysis, the cost structure of Norwegian aluminium plants is estimated using a flexible translog cost function approach with no a priori restrictions on scale or substitution elasticities. Plant-level panel data over 1972-1993 are applied. The importance of product specialisation for the development in costs and producer prices is examined. Hence, important a priori assumptions on both the cost structure and price in earlier work on the aluminium industry are tested. Plant specific margins are calculated using observed producer prices and estimates of marginal costs.

Section two presents the estimated cost function, section three the analysis of the Norwegian producer prices, while section four presents the margins measured by the Lerner index. The main findings are summarised in the final section.

2. The estimated cost function

We model variable costs using the flexible translog cost function suggested by Christensen et al. (1971, 1973), which can be interpreted as a quadratic approximation to a general continuous twice-differentiable function. Labour, raw materials and electricity are treated as variable inputs, while capital is assumed to be a quasi-fixed, or predetermined, factor, due to the long lead time needed to build new capacity. We also treat output as a predetermined factor in our analysis, since Norwegian aluminium plants in general enter into long-term contracts that specify quantities. The weak exogeneity assumption of capital and output is tested, however. We use plant-level panel data, and plant-specific dummy variables and a trend variable are included, so that the general cost function captures permanent differences in technology or efficiency across plants (fixed effects) as well as technical innovation over time. We test if the innovation process is plant or company specific rather than being common to the industry.

In their analysis of the North American aluminium industry, Bresnahan and Suslow (1989) argue that the industry short-run marginal cost curve is right angled at the capacity. In accordance with this, we design our general model so that the curvature of the marginal cost curve may be very steep close to the capacity. Because some plants have increased their capacity by re-smelting and upgrading of second-grade aluminium in addition to an increase in the primary capacity, we test for heterogeneity in the curvature of the marginal cost curve close to the capacity. Several plants in our sample report production of first transformation and casting of aluminium in addition to primary aluminium, which is the main output. Our general cost function therefore includes a variable that reflects the degree of processing by each plant, and we expect to find a positive effect from an increase in the degree of processing on variable costs if the product mix is important. Because the quality of the disaggregated production data used to calculate the degree of processing variable varies across plants, we formulate this effect to be heterogeneous across plants in the general case.

Although the Norwegian primary aluminium industry is dominated by two companies, we assume that variable input decisions are taken at the plant level. Given the capacity and the level of output, each plant is assumed to minimise variable costs. Our most general cost function is given in equation (2.1).

$$
\begin{aligned}
(2.1)\qquad \ln C_{ft} = {} & \gamma_{0f} + \Sigma_i\, \alpha_{if} \ln Q_{ift} + 1/2\, \Sigma_i \Sigma_j\, \beta_{ij} \ln Q_{ift} \ln Q_{jft} + \gamma_X \ln X_{ft} + 1/2\, \gamma_{XX} (\ln X_{ft})^2 + \\
& \Sigma_i\, \gamma_{iX} \ln Q_{ift} \ln X_{ft} + \gamma_K \ln K_{ft} + 1/2\, \gamma_{KK} (\ln K_{ft})^2 + \Sigma_i\, \gamma_{iK} \ln Q_{ift} \ln K_{ft} + \gamma_{XK} \ln X_{ft} \ln K_{ft} + \\
& \gamma_{Tf} \ln T_t + 1/2\, \gamma_{TT} (\ln T_t)^2 + \Sigma_i\, \gamma_{iT} \ln Q_{ift} \ln T_t + \gamma_{XT} \ln X_{ft} \ln T_t + \gamma_{KT} \ln K_{ft} \ln T_t + \\
& \gamma_{CAPf}\, D_{ft} \ln X_{ft} + \gamma_{91f}\, D91_t \ln T_t + \gamma_{DPf} \ln XP_{ft} + \Sigma_i\, (\varepsilon_{ift} + \zeta_{if}) \ln Q_{ift} + u_{ft}
\end{aligned}
$$

$i,j=L, M, E,\ \ f=1,..,N$

Subscript t, f and i,j denote period, plant and input respectively, where i,j=L (labour), M (raw materials), and E (electricity); C_f is total variable costs of plant f; Q_{if} is the price of input i faced by plant f; X_f is the output of plant f measured in tonnes; K_f is the capital stock in plant f; T is a deterministic time trend intended to proxy the level of technology; D_f is a dummy variable that is one in periods where the primary capacity utilisation ratio is 0.97 or above and zero elsewhere; D91 is a dummy variable that is zero up to 1990 and one from 1991. This variable captures the effects of programs initiated in the second half of the eighties with the aim to increase the productivity; XP_f is a variable that represents the degree of processing in plant f, and is measured as production of first transformation and casting of aluminium relative to total output; u_f are stochastic error terms; ε_{if} are equilibrium errors of the cost-share equations (to be explained later); The α's, β's, γ's and ζ's are coefficients. We assume that

$$E[(u_{ft})(u_{es})'] = \begin{cases} \Omega & \text{for } t = s \text{ and } f = e, \\ 0 & \text{otherwise.} \end{cases}$$

Our data-set includes seven Norwegian plants over 1972-1993 and an additional plant that was closed down in 1981. The data and empirical variables are defined in the appendix. All regressions start in 1974. We use the full information maximum likelihood procedure (FIML) in TROLL, and a small sample adjusted χ^2-form of the likelihood ratio test is applied in a general to specific search.[2]

The plants are assumed to be price-takers in variable input markets, and applying Shepard's Lemma to (2.1) gives the cost-share equation for each variable input. In Lindquist (1995), a multivariate error-correction model of the cost shares of labour, raw materials and electricity was estimated.[3] The long-run coefficients in the cost-share equations, that is the α_{if}'s, β_{ij}'s, γ_{iX}'s, γ_{iK}'s and γ_{iT}'s, are used as a priori restrictions when estimating the cost function in (2.1). We also include the equilibrium errors (ε_{ift}) of the cost-share equations, i.e. the actual cost shares minus the predicted cost shares from the long-run relationships. By definition, these equilibrium errors sum to zero, i.e. $\Sigma_i\varepsilon_{ift}=0$. Due to a normalisation of the explanatory variables in Lindquist (1995), which is not maintained when estimating the cost function, we need to estimate corresponding coefficients to the α_{if}'s freely. We

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[2] $\chi^2(j) = -2(\Theta-k_1-1+j/2)/\Theta \cdot[\ln L_0 - \ln L_1]$, where Θ 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).

[3] The key findings according to the preferred error-correction cost-share equation model in Lindquist (1995) were: The conditional cost function is homogeneous of degree one in input prices ($\Sigma_j\beta_{ij}=0$), and cross-price effects are symmetric ($\beta_{ij}=\beta_{ji}$). The production technology is homothetic ($\gamma_{iX}=0$), and the technical progress is Hicks-neutral ($\gamma_{iT}=0$). The input coefficient for electricity is independent of the level of capital stock ($\gamma_{EK}=0$; $\gamma_{MK}=-\gamma_{LK}$). 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. Due to a normalisation of the explanatory variables, the α_{if}'s were restricted to equal the plant specific cost shares in 1972.

denote these coefficients ζ_{if}, and because cost shares add to unity, we include the restriction that $\Sigma_i\zeta_{if}=1$.

Estimating the general cost function with all the restrictions from step one and the ε_{ift}'s as predetermined variables gives a standard error of regression of 17 per cent. If we exclude the ε_{ift}'s, the standard error decreases to 6 per cent, and this decline in the standard error is a robust result that holds also in our preferred cost function. We therefore simplify the model and exclude the predetermined equilibrium errors from the regressions.

The preferred cost function is shown in table 2.1. Table 2.1 includes the industry average cost shares in 1972, $\alpha_{i,1972}$, rather than all the plant specific cost shares. In addition to the conclusions from the estimated cost-share equations, the cost function in table 2.1 implies increasing returns to scale with respect to variable inputs. If variable inputs increase by one per cent, output increases by 1.25 per cent. The elasticity of scale equals the inverse elasticity of costs with respect to output, which is 0.80. The hypothesis of constant returns to scale up to the capacity constraint; $\gamma_X=1$, is clearly rejected by the likelihood ratio test. The χ^2-statistic equals 13.840, and the null (constant returns to scale) hypothesis is rejected at a significance level close to zero. According to our results, using average variable costs as a proxy for marginal cost involves a measurement error of around 20 per cent. The two cost measures develop proportionally, and hence the measurement error increases with marginal cost.

The economies of scale property implies that production of aluminium is more efficient in large than in small plants, as argued by the industry itself. For example the need for continuously control of the smelting process is one source to economies of scale, because the number of workers needed for this activity does not increase proportionally with the level of output. However, there may well be a particular level of output, outside the observed range in our sample, above which the aluminium plants would operate under decreasing returns to scale. In Sand et al. (1992) it is argued that the optimal capacity of a new plant built in 1992 was 200000 tonnes aluminium per year. Our sample includes very few observations with a capacity above this level, which may explain why we find such strong evidence for increasing returns to scale. The exploitation of the scale economies has increased over time, however, as a consequence of a positive trend in output levels.

The hypothesis that the curvature of the marginal cost curve is very steep *close* to the capacity constraint is also rejected, and γ_{CAPf} f=1,..,8 are restricted to zero. This conclusion is robust to alternative definitions of a "high capacity utilisation ratio", that is, to limits above or below 0.97. This is not a rejection of a right angled marginal cost curve *at* the capacity, however. Our results imply that it is possible to exploit the economies of scale up to the capacity, and if the marginal cost curve is right angled or very steep in this point, plants will not produce above this limit, and hence we are not able to identify this part of the

Table 2.1. The estimated cost function

Coefficient[1]	Estimate	Coefficient	Estimate	Restrictions from the cost-share equations and industry average cost shares in 1972	
γ_{01}	3.43 (.59)	ζ_{L1}	-0.28 (.13)	$\alpha_{L,1972}$	0.22
γ_{02}	4.60 (.68)	ζ_{L2}	-0.49 (.12)	$\alpha_{M,1972}$	0.60
γ_{03}	2.60 (.69)	ζ_{L3}	-0.15 (.12)	$\alpha_{E,1972}$	0.18
γ_{04}	4.66 (.66)	ζ_{L4}	-0.35 (.09)	β_{LL}	0.05
γ_{05}	4.47 (.61)	ζ_{L5}	-0.43 (.08)	β_{LM}	-0.05
γ_{06}	4.22 (.48)	ζ_{L6}	-0.32 (.09)	β_{LE}	0
γ_{07}	4.20 (.57)	ζ_{L7}	-0.50 (.11)	β_{MM}	0.14
γ_{08}	6.31 (1.98)	ζ_{L8}	-0.25 (.42)	β_{ME}	-0.09
γ_{X}	0.80 (.05)	ζ_{M1}	0.41 (.10)	β_{EE}	0.09
γ_{XX}	0 *	ζ_{M2}	0.69 (.13)	γ_{LX}	0
γ_{K}	*[2]	ζ_{M3}	0.01 (.13)	γ_{MX}	0
γ_{KK}	0 *	ζ_{M4}	0.56 (.08)	γ_{EX}	0
γ_{XK}	0 *	ζ_{M5}	0.53 (.09)	γ_{LK}	-0.18
γ_{Tf}	0.16 (.03)	ζ_{M6}	0.48 (.12)	γ_{MK}	0.18
γ_{TT}	0 *	ζ_{M7}	0.60 (.10)	γ_{EK}	0
γ_{XT}	0 *	ζ_{M8}	0.74 (.39)	γ_{LT}	0
γ_{KT}	0 *			γ_{MT}	0
γ_{CAP}	0 *			γ_{ET}	0
γ_{91}	-0.03 (.01)				
$\gamma_{DP,f}$	0.18 (.05)				
$\gamma_{DP,f}$	0.45 (.14)				
lnL = -1744.79 DF = 11		$R^2 = 0.994$ SER = 0.067		DW = 1.790 $\chi^2(34) = 40.987$ (19%)	

Estimation period: 1974-1993. Standard errors in parentheses. lnL is the value of the log-likelihood function. DF is 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) γ_{Tf} is included in the cost function for two of the plants. $\gamma_{DP,f}$ is included for two other plants. For the reason of anonymity, we can not specify which plants.

2) $\gamma_K = -\gamma_{LK}\ln(Q_{Lft}/Q_{Mt})$, 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.

marginal cost curve empirically.

The cost function in table 2.1 includes two effects of investments in increased capacity on variable costs. By restriction the two effects cancel out, i.e. $\gamma_K = -\gamma_{LK}\ln(Q_{Lft}/Q_{Mt})$, which implies that $\partial \ln C_{ft}/\partial \ln K_{ft}=0$. When testing this zero capital-effect restriction we get $\chi^2(1)=4.176$, and the restriction is rejected at the 5 per cent significance level, but accepted at the 4 per cent level. Although not supported very strongly statistically, we accept the zero capital-effect restriction, mainly because the capital-effect on costs (calculated at the sample mean) is found to be positive when estimated freely. A positive capital effect is in conflict with the regularity conditions on the cost function. Capacity expansions affect the input mix, however, and the input of labour decreases while the input of raw materials increases. (The constant returns to scale restriction is tested and rejected also when the capital effect is not restricted to zero.)

We expected to find a negative trend effect if technological innovations have been important for the development in variable costs. However, estimated trend effects should be interpreted with care. Econometric models are in general simplifications of the reality, and a trend may pick up effects of excluded variables and in that case represents the net effect of several factors. We find a negative trend effect from 1991 on, which we interpret as a result of programs initiated by Hydro and Elkem in the second half of the eighties with the aim to increase productivity. These programs are described in their annual reports. Significant negative trend effects prior to 1991 is not found, which may be due to cost increasing effects that have cancelled out technical change effects. First, costs have increased in the Norwegian aluminium industry due to environmental expenditures to meet increasingly severe pollution restrictions. And second, increased product differentiation not reflected by the degree of processing variable may also have increased variable costs. It is difficult to identify empirical measures for these effects, however, and they are therefore not explicitly included in the model.

For most plants the effect of the degree of processing variable on variable costs is positive, but the estimated coefficient is significant for only two of them. We face a problem with the quality of the disaggregated production data used to calculate the degree of processing variable, however, because not all plants are consistent in how they classify their output mix over time. This inconsistency problem may explain why we do not find a significant effect of this variable for more plants, and may also explain why we find a positive trend effect for two plants. This positive trend effect may partly reflect a change in the product mix that is not correctly reported by the plants. Furthermore, if product differentiation is due to variation in quality, customer service or delivery conditions, this will in general not be picked up by the degree of processing variable but rather by a trend.

In addition to being homogeneous of degree one in input prices and increasing in output, as already shown, the cost function must be non-decreasing and concave in prices of variable inputs and non-increasing and convex in capital to be well behaved, cf. Brown and Christensen (1981, p. 217-218) and Jorgenson (1986, p. 1885). Lindquist (1995) concludes that most sample points support the "non-decreasing and concave in prices" condition. The mean industry own-price elasticities are negative in all years. The requirements with respect to capital are satisfied in all sample points by restriction. To test the assumptions that output and capital are weakly exogenous in the cost function, we use the Hausman-Wu test procedure, cf. Godfrey (1988). We get $\chi^2(1)=0.915$ for output and $\chi^2(1)=0.154$ for capital, and the null hypothesis is rejected at the 34 and 69 per cent significance level respectively. We conclude that weak exogeneity is not rejected in this case.

3. Price determination

Gilbert (1995) argues that aluminium producers compete on quantity, grade and delivery conditions but not on price. This is consistent with what Norwegian aluminium plants report; their prices are closely tied to the LME-price, but due to product differentiation most plants sell at a premium. An analysis of Norwegian producer prices can help us to understand the process between the LME-price and the Norwegian producer prices and give important information about the strategies applied by Norwegian plants to offset the increased competition effect. We are particularly interested in testing if Norwegian producer prices follow the same trend as the LME-price. A comparison of Norwegian producer prices and the price on deliveries in three months quoted on the LME of 99.7 per cent ingot aluminium (3-month LME-price) reveals important price variation. This is true both across Norwegian producer prices and|across the LME-price and Norwegian producer prices. Figure 3.1 shows he output weighted average of Norwegian producer prices and the 3-month LME-price measured in Norwegian kroner (NOK).[4]

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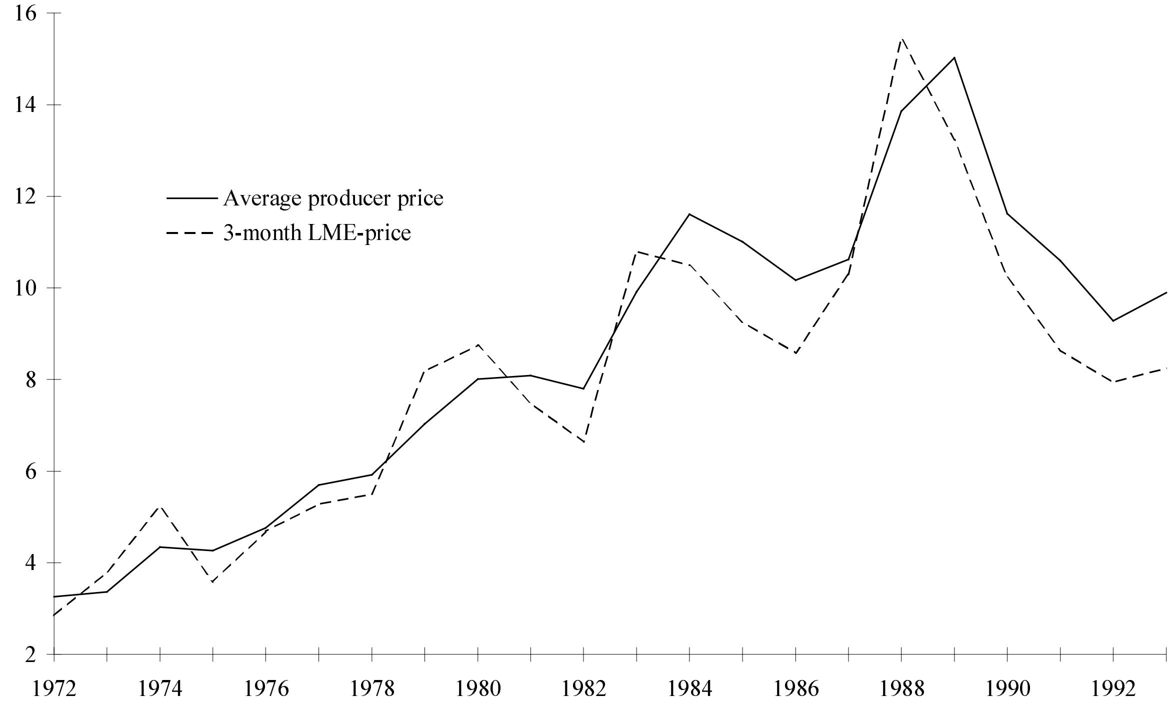
[4] The 3-month price for the whole sample period was provided to us by Hydro Aluminium. We choose the 3-month rather than the cash LME-price as a reference price, because Norwegian plants generally sell their output on long-term contracts. These two LME-prices move very closely, however. Data prior to 1979 are based on quoted producer prices by leading plants.

Figure 3.1. The output weighted average of Norwegian producer prices and the 3-month price of primary aluminium quoted on the London Metal Exchange (LME), 1000 NOK/tonne



The variation in prices may reflect:

(i) Vertical (quality) differentiation, that is, variation in the purity of the aluminium.

(ii) Horizontal differentiation that may be due to different shapes, semi-manufactures, customer tailored products, and variation in customer service or reliability of delivery.

(iii) Internal pricing strategies for vertically integrated plants.

(iv) The extensive use of long-term contracts made by Norwegian aluminium plants at different points in time and with different price agreements. These contracts may involve fixed prices or prices linked in various ways to the LME-price at the time of delivery.

While (i) and (ii) imply that Norwegian producer prices may permanently differ from the LME-price with a premium, (iv) implies that Norwegian producer prices should equal the LME-price in the long-run. They may lag behind though. The effect of (iii) depends on whether the companies use the LME-price as a reference price in their internal pricing strategy or not.

We specify Norwegian producer prices as functions of the 3-month LME-price, a constant term, a trend variable, the degree of processing in each plant and the prices of electricity and labour input.

The constant term is assumed to represent a permanent premium in Norwegian producer prices, and would imply a stable degree of product differentiation. If product differentiation or specialisation has increased over time, we expect the premium to increase, and we should find a positive coefficient on the degree of processing variable and/or a positive trend effect. The trend is included to pick up changes in product differentiation that is not reflected in the degree of processing variable. Scale economies and differentiated products imply imperfect competition, and it is of interest to test if variation in domestically determined input prices is carried over to the producer prices. We therefore include the prices of electricity and labour in the general price equations. The price of the international traded raw material alumina, which is the most important raw material in the aluminium industry, is highly correlated with the international aluminium price and not included in the general model.

Because it is important to allow for short-run discrepancies between the Norwegian producer prices and the LME-price, we estimate an error-correction model. This specification is well suited to our purpose, since it is simple to test restrictions on the long- and short-run separately. Our most general error-correction model is given in equation (3.1), and the corresponding long-run relationship is given in equation (3.2). The general model consists of eight plant specific price equations, i.e. there are no restrictions on coefficients across the plants a priori. The motivation for this general framework is that the price process may vary across the plants because long-term agreements may differ and because products may be differentiated in various ways. Only restrictions that are accepted by the likelihood ratio test are included in the final model. Lower case letters indicate that the variables are in logarithms, and $\Delta a_t = \ln(A_t/A_{t-1})$ is the first difference of the logarithm of the variable A.

$$\Delta p_{ft} = \eta_{0f} + \eta_{1f}\,\Delta p_{f,t-1} + \eta_{2f}\,\Delta pw_t + \eta_{3f}\,\Delta pw_{t-1} + \eta_{4f}\,\Delta xp_{ft} + \eta_{5f}\,\Delta q_{Eft} + \eta_{6f}\,\Delta q_{Lft} \tag{3.1}$$
$$+ \mu_{Pf}\,(p_{f,t-1} - pw_{t-1}) + \mu_{Xf}\,xp_{f,t-1} + \mu_{Ef}\,q_{Ef,t-1} + \mu_{Lf}\,q_{Lf,t-1} + \mu_{Tf}\,T_{t-1} + v_{ft}$$

$$(p_f - pw) = \tau_{0f} + \tau_{Xf}\,xp_f + \tau_{Ef}\,q_{Ef} + \tau_{Lf}\,q_{Lf} + \tau_{Tf}\,T + \varepsilon_f \tag{3.2}$$

where $\tau_{0f} = -\eta_{0f}/\mu_{Pf}$, $\tau_{Xf} = -\mu_{Xf}/\mu_{Pf}$, $\tau_{Ef} = -\mu_{Ef}/\mu_{Pf}$, $\tau_{Lf} = -\mu_{Lf}/\mu_{Pf}$, $\tau_{Tf} = -\mu_{Tf}/\mu_{Pf}$; P_f is the producer price of plant f (excl. freight and forwarding costs); PW is the 3-month LME-price; T is a deterministic time trend; v_f are individual random errors, which we assume are white noise; ε_f are equilibrium errors.

If aluminium is a homogeneous good, we expect Norwegian producer prices excl. freight and forwarding costs to equal the LME-price in the long-run, i.e. a particular customer should pay the same price independent of producer. In this case, no other variables than the LME-price should enter the price equations, neither should the constant term. Short-run discrepancies may prevail because of the use of long-term contracts. A rejection of the long-run price equalisation hypothesis implies that products are differentiated and that specialisation is important, or that the price on internal deliveries are not tied to the LME-price. On the basis of discussions with representatives from the industry, we rule out the latter as an important explanation.

The final results are presented in table 3.1. The estimated price equations are found to differ across the plants, but for the reason of anonymity, we are not allowed to specify the plant specific price equations in detail. Below each coefficient in the table, the number of price equations the coefficient enters is given in square bracket parentheses.

We find long-run homogeneity between all Norwegian producer prices and the LME-price, i.e. a one per cent increase in the LME-price gives a one per cent increase in Norwegian producer prices in the long-run. To reject long-run homogeneity, one must accept a 33 per cent significance level. There are important short-run discrepancies, however, and the impact effect on own-price of a one per cent

Table 3.1. The relationship between Norwegian producer prices and the 3-month LME-price

$\Delta p_{ft} =$	0.13	$+ 0.56\ \Delta pw_t$	$+ 0.28\ \Delta xp_{ft}$	$- 0.53\ (p_{f,t-1}-pw_{t-1})$	$- 0.73\ (p_{f,t-1}-pw_{t-1})$	$- 1.00\ (p_{f,t-1}-pw_{t-1})$
	(.02) [1]	(.02) [8]	(.13) [1]	(.06) [2]	(.06) [4]	(*) [2]
	$+ 0.025\ T_{t-1}$	$+ 0.019\ T_{t-1}$				
	(.003) [3]	(.004) [3]				

Likelihood ratio tests:[1]
Against the most general model: $\chi^2(89) = 82.655$ (67%)
Long-run price homogeneity: $\chi^2(8) = 9.094$ (33%)
No effects of labour costs: $\chi^2(8) = 5.300$ (73%)
No effects of electricity prices: $\chi^2(8) = 9.314$ (32%)
No trend effects: $\chi^2(2) = 59.513$ (0%)

lnL = -102.43	Estimation period: 1974-1993	SER = 0.060
DF = 141	$R^2 = 0.84$	DW = 2.040

Standard errors in parentheses. Estimated coefficients are found to differ across plants, and under each coefficient the number of plants with that coefficient in its price equation is given in square bracket parentheses. For the reason of anonymity, we can not specify which plants.

1) The small sample $\chi^2(j)$-statistic (cf. Mizon, 1977), j denotes the number of restrictions, and the significance level where the null hypothesis is rejected is given in parentheses. The accepted price model is the null hypothesis in the first four tests and the alternative hypothesis in the last test.

* Restriction supported by likelihood ratio test.

increase in the LME-price is 0.6 per cent. The adjustment to changes in the LME-price is relatively rapid for all plants, and the cumulative effect at t+1 shown by the standardised interim multiplicator is as much as 0.8-1.0 per cent. These results support the hypothesis that much of the observed price differences are due to long-term contracts with varying price conditions made by Norwegian plants and that Norwegian producer prices are closely tied to the LME-price.

We find no significant effect of domestically determined prices of variable inputs, which means that variation in labour costs and electricity prices is not carried over to the producer prices. However, the results support the differentiated products hypothesis for all the seven plants that exist over the whole sample period; For one plant we find a significant constant term, and for the other six plants we find significant trend effects. I.e. for most plants the producer price has increased more rapidly than the international reference price. Due to price homogeneity and zero effects of labour costs and electricity prices, we conclude that products are relatively close substitutes. For a chosen product or quality, the price is determined by the LME-price and a sustainable mark-up on this price, and variation in domestically determined input prices is carried over to the margins and not to the producer prices.

4. The Lerner indices

When analysing the margins of the aluminium plants we use the Lerner index (Lerner, 1934); $L_{ft} = [P_{ft} - \partial C_{ft}(.)/\partial X_{ft}]/P_{ft}$. This normalised measure of the price-cost margin is convenient for comparisons particularly over time. The plant specific Lerner indices are calculated by using the estimated cost functions in table 2.1, predicted variable costs and observed output and producer prices (excl. freight and forwarding costs). The Lerner index is frequently used in the literature as a measure of market power by a firm or industry. Standard assumptions imply that $[P_f - \partial C_f(.)/\partial X_f] \geq 0$ and $\partial C_f(.)/\partial X_f \geq 0$, hence $0 \leq L_f \leq 1$. The larger is L_f, the larger is the market power, and if $L_f = 0$ (price equals marginal cost) plant f has no market power. Table 4.1 gives the mean, maximum and minimum values over the period 1972 to 1993 in addition to the standard deviation of the plant specific margins.

Table 4.1. Calculated Lerner indices (L_f) over the period 1972-1993

	Mean[1]	Maximum[1]	Minimum[1]	St.dev.	Correl(L_f, IPDT)[2]	Unit-root tests[3]
Plant 1	0.42 (.03)	0.55 (.03)	0.28 (.04)	0.08	0.35	-3.05 DF *
Plant 2	0.28 (.04)	0.47 (.03)	0.12 (.05)	0.11	0.21	-2.77 ADF
Plant 3	0.39 (.04)	0.53 (.03)	0.24 (.05)	0.08	0.33	-4.57 ADF **
Plant 4	0.42 (.03)	0.54 (.03)	0.30 (.04)	0.06	0.31	-3.42 DF *
Plant 5	0.43 (.03)	0.56 (.03)	0.29 (.04)	0.07	0.36	-5.20 ADF(T) **
Plant 6	0.48 (.03)	0.57 (.03)	0.39 (.04)	0.05	0.50	-3.54 ADF *
Plant 7	0.43 (.03)	0.52 (.03)	0.23 (.05)	0.08	0.37	-3.68 DF *
Plant 8	0.26 (.04)	0.47 (.04)	0.04 (.06)	0.13	0.62	-1.90 DF
Industry[4]	0.42 (.03)	0.51 (.03)	0.31 (.04)	0.06	0.43	-3.63 ADF *

1) The standard error of the Lerner indices in parentheses. When calculated, average variable costs and prices are treated as deterministic variables. The standard error of the industry Lerner index is the mean of the standard error in each sample point.

2) Correlation between the Lerner indices (L_f) and the detrended industry production in OECD (IPDT). The latter variable is a proxy for fluctuations in demand around a trend. IPDT is found by regressing the original data on a linear trend and subtracting this trend effect from the original data.

3) * and ** denote that the hypothesis "non-stationary margins" is rejected at 5% and 1% respectively. DF is the Dickey-Fuller test with a constant. ADF is the augmented Dickey-Fuller test with one lag and a constant. ADF(T) includes in addition a deterministic trend. Critical values are for the DF test -3.01 (5%) and -3.79 (1%), for the ADF test -3.02 (5%) and -3.81 (1%), and for the ADF(T) test -3.66 (5%) and -4.50 (1%). For plant 8 the critical value is -3.27 (5%).

4) The output weighted average of the Lerner indices of Norwegian plants.

The margins are significantly above zero in all sample points, and hence in both trough and peak periods. The simple competitive model with price equal to marginal cost is rejected, as was expected because of increasing returns to scale. The mean margin is above 0.4 for most plants. Heterogeneity in both prices and marginal costs gives rise to intra-industry variation in the margins. The somewhat lower margins of plant 2 and 8 in table 4.1 are largely due to a cost disadvantage, that is a high marginal cost, which reflects that these plants are rather small. In addition, the average prices of these plants are relatively low. (One of these plants was closed down in 1981.) The relatively high margin of plant 6 is due to a high price.

In an attempt to reveal the importance of economies of scale, we compare the margins based on marginal costs with margins based on average variable costs. The industry margin based on average variable costs equals 0.27, which is 36 per cent below the industry margin based on marginal costs.

Hence, economies of scale are important for explaining the positive margins in this industry. It is also of interest to understand how the margins fluctuate over the business cycle, and table 4.1 includes the correlation between the margins and the detrended industrial production in OECD (IPDT). The latter variable is assumed to reflect deviation in demand from its trend path, i.e. to reflect the business cycles. Support is found for a procyclical margin, and the industry margin is clearly procyclical.[5]

Our industry margin based on marginal cost is above the margin found in earlier analyses. Using data on the U.S. aluminium industry over the period 1949-1981, Domowitz et al. (1987) find a margin equal to 0.32. Klette (1990) uses data on the Norwegian aluminium industry over the period 1972-1986 and finds a margin equal to 0.22. Both analyses use margins based on average variable costs, however.

We now turn to the development in the margins over time. Due to the decline in industry concentration internationally, one may expect the margins to follow a negative trend as new and possibly more efficient plants enter the market. The large increase in exports from former Soviet republics in later years has contributed to the downward pressure on the margins. Our impression from figure 4.1, which shows the plant specific margins, is that most margins oscillate around constant levels. In that case, the margins are stationary variables. If the margins follow a negative trend they are non-stationary variables.

We test the hypothesis that the margins are non-stationary against the alternative hypothesis that the margins are stationary, cf. Dickey and Fuller (1979) and Engle and Yoo (1987). We use PcGive 9.0 (see Hendry and Doornik, 1994), and start with a general augmented Dickey-Fuller (ADF) test with two lags, a constant and a deterministic trend. The results are reported in the last column of table 4.1, where a significant test supports the hypothesis that the margins are stationary. At the five per cent significance level, the hypothesis of non-stationary margins is rejected for six plants and for the industry average. The deterministic trend effect for plant 5 is positive.

Figure 4.1. The Lerner indices of Norwegian aluminium plants

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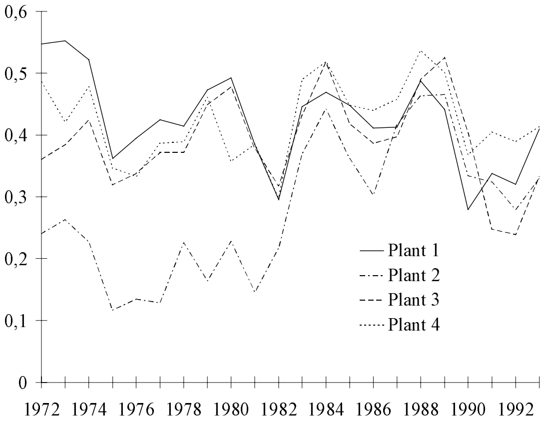
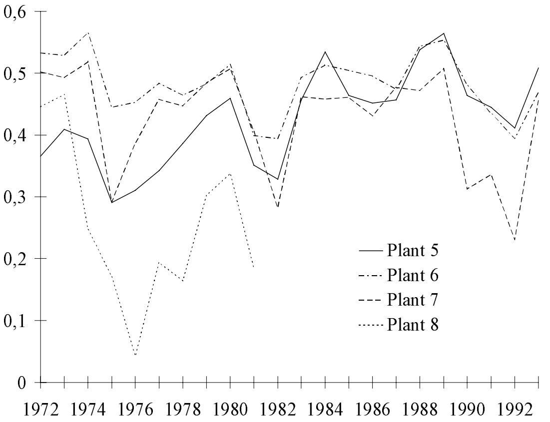
[5] This is consistent with Domowitz et al. (1986), who find procyclical margins in concentrated industries. Chirinko and Fazzari (1994), who analyse a panel of firm-level data, conclude that "when market power varies temporally, it is usually procyclical". On the other hand, analyses of U.S. data at 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.

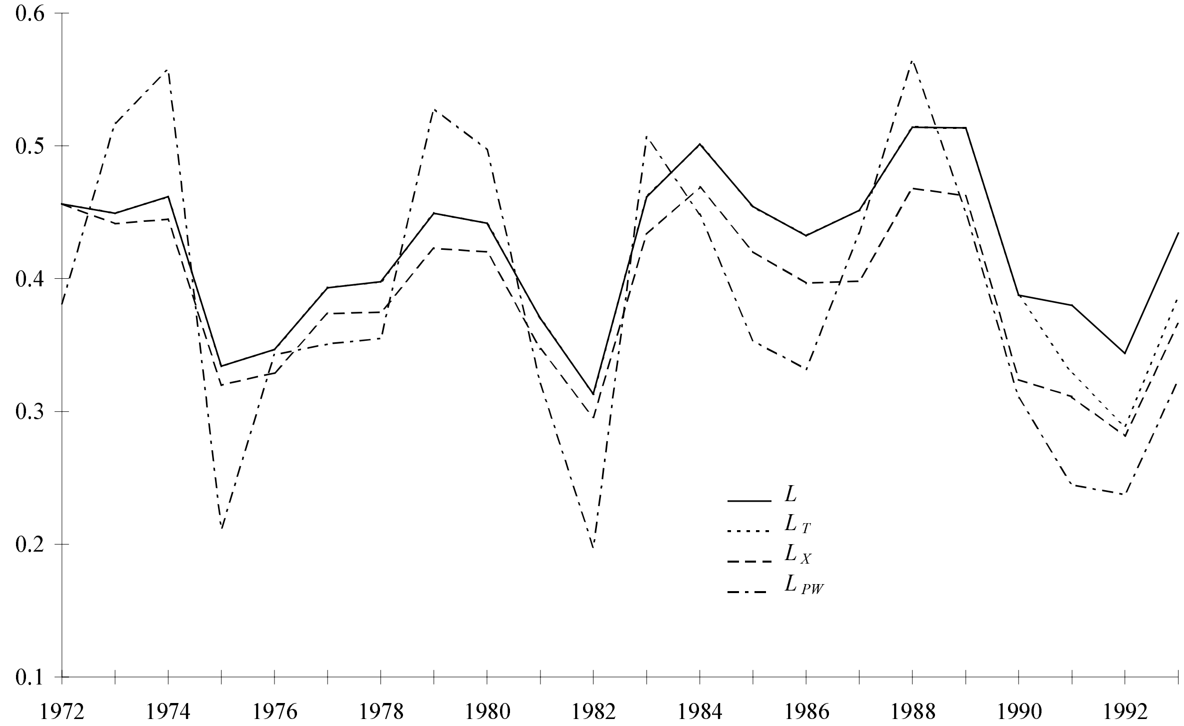




Since the margins fluctuate around constant levels or a positive trend, we conclude that a downward pressure on the margins from the increase in the degree of competition internationally has been cancelled out by other effects of importance. We have identified three effects: First, in section 2 we found that the plants have increased productivity and reduced costs during the nineties. Second, Norwegian aluminium plants have in general increased their level of output over time, and due to the presence of economies of scale, this has reduced marginal costs. And third, in section 3 we found that the producer price of most plants has increased more rapidly than the LME-price. This is interpreted as being due to an increase in the degree of product specialisation over time.

To understand the importance of the different effects for the margins, we calculate and compare the margins under different assumptions. Figure 4.2 shows the development in the industry margin in the various cases. Excluding the negative trend effect affects the average industry margin very little, because it enters the cost functions only in the last three years. When excluding this effect, the industry margin equals 0.415 which should be compared to 0.422. The trend effect is important for the development in the nineties, however. The importance of growth in output in combination with increasing returns to scale is analysed by keeping the output levels constant at the 1972-levels when calculating the margins. In this case we get an industry margin equal to 0.39. If we use the 3-month LME-price rather than the Norwegian producer prices, we get an industry margin equal to 0.38. In this case the margins are more volatile, which shows that the strategies applied by Norwegian plants, and their customers, involve more stable prices than the LME-price.

Figure 4.2. The industry Lerner index under different assumptions. L: No restrictions; L_T: No negative trend effect; L_X: Output constant at the 1972-level; L_{PW}: Price equal to the 3-month LME-price



If we include all three restrictions simultaneously, we get an industry margin equal to 0.33, which is 24 per cent below the industry margin of 0.42. The better exploitation of the scale economies over time and the increase in Norwegian producer prices relative to the LME-price are equally important for the stability in the margins according to our results.

However, even though aluminium plants have managed to offset the negative effect on the level of the margins from the increase in the degree of competition internationally, changing market structure may have affected the margins in other important ways. Slade (1991) concludes that the change in price determination from producer-based prices, where aluminium was sold at list prices announced by the major producers, to a system where the LME-price is the reference price for most trade in aluminium, has increased the price-instability. As a consequence, we expect the variability of Norwegian producer prices to increase over time. The effect of this on the margins depends on the variability in both prices and marginal costs. To examine how the variability in the margins develops over time, we split our sample in three sub-periods and calculate the variance of the margins in each sub-period. The results at the industry level are given in table 4.2, which also reports the variability in producer prices and marginal costs at the industry level. Because of the non-stationary nature of these two latter

Table 4.2. The variance in selected sub-periods of the industry Lerner index (*L*), percent changes in the industry producer price (P) and marginal cost (MC)

	$\mathrm{var}(L)\cdot 10^3$			$\mathrm{var}[\ln(P_t/P_{t-1})]\cdot 10^2$			$\mathrm{var}[\ln(MC_t/MC_{t-1})]\cdot 10^2$		
	1972-79	1980-86	1987-93	1973-79	1980-86	1987-93	1973-79	1980-86	1987-93
Industry	2.6	4.0	4.4	0.9	1.5	2.9	1.5	3.6	4.8

variables, we use the variance of percent changes in prices and marginal costs as a measure of instability. I.e., for each sub-period, we use the approximation $\mathrm{var}[\ln(V_t/V_{t-1})]$ as a measure of instability in prices and marginal costs.

Table 4.2 shows that the instability in the margins in general is higher in the eighties and beginning of the nineties than in the seventies. Consistent with the conclusion in Slade (1991), the variance of percent changes in the producer prices shows a clear positive trend over the three sub-periods. The same is true also with respect to the variance of percent changes in marginal costs. There are exceptions to this pattern at the plant level, however.

Our overall conclusion is that Norwegian aluminium plants have managed to neutralise the downward pressure on the margins from changing market structure over the period 1972 to 1993. A higher variance of the margins implies that plants face a higher risk of seeing years with very small profit margins.

5. Final remarks

The paper analyses if changing market structure internationally has affected the margins of Norwegian aluminium plants. Margins are measured by the Lerner index, i.e. as price minus marginal cost divided by price, using estimated measures of marginal costs and observed producer prices. The key findings are:

1. The margins of Norwegian plants oscillate around constant levels. Hence, the downward pressure on the margins from increased degree of competition in the aluminium market has been offset. The paper finds that this is very much due to a better exploitation of scale economies over time and that Norwegian producer prices have grown more rapidly than the LME-price as a result of product specialisation. In addition, the aluminium plants have increased their productivity during the nineties. The variability of the margins has increased over time, however.

2. The margins are significantly above zero in both trough and peak periods, a result that is incompatible with the simple competitive hypothesis. The margins move procyclically over the business cycle, and heterogeneity in both prices and marginal costs give rise to intra-industry variation in the margins. Economies of scale are important for explaining the positive margins.

3. The observed deviation of Norwegian producer prices from the LME-price is partly due to the use of long-term contracts by Norwegian plants. Long-run homogeneity between Norwegian producer prices and the LME-price is supported by the data. I.e., a one per cent increase in the LME-price increases Norwegian producer prices by one per cent. The adjustment process is relatively quick. The hypothesis of differentiated products is accepted, however, because Norwegian producer prices in general are found to grow more rapidly than the LME-price. Homogeneity between prices is assumed to reflect that the products are relatively close substitutes, and for a chosen product or quality, the price is determined by the LME-price and a sustainable mark-up on this price.

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Appendix A

The data and empirical variables

Primarily we use data from the manufacturing statistics data base at Statistics Norway, which follows the Standard Industrial Classification (SIC) and gives annual data for firms at the 5-digit code. We use data for industry 37201. NNA denotes the Norwegian National Accounts.

C_f	Total variable costs of plant f, 1000 NOK.
Q_{Lf}	Labour costs in NOK per man hour for plant f.
Q_M	Price of raw materials to the Norwegian aluminium industry, 1989=1. NNA-data.
Q_{Ef}	Price of electricity measured in øre per kWh for plant f.
X_f	Output of plant f, tonnes aluminium.
XP_f	The degree of processing in plant f, measured as production of first transformation and casting of aluminium relative to total output.
K_f	Capital stock of plant f. Defined as the (primary) output capacity measured in tonnes aluminium per year adjusted to include additional capacity due to re-smelting and up-grading of imported second-grade aluminium. Data reported by the plants upon request.
P_f	The producer price of plant f , calculated as the production value excl. freight and forwarding costs divided by the production volume.
PW	The 3-month LME-price. Prior to 1979 this variable is based on producer prices quoted by leading aluminium plants internationally. Data provided to us by Hydro Aluminium.
T	A deterministic linear trend variable, 1972=1.

- The price of raw materials (Q_M) is not available at the plant level for all years in our sample, and we are therefore forced to use national account data at the industry level. If plants face different prices of raw materials, we face a measurement error problem. Alumina, which is the major raw material, is an internationally traded commodity, and it is reasonable to assume that plants face similar prices of this raw material.
- The electricity prices (Q_{Ef}) are determined by favourable long-term electricity contracts with national power plants, which include agreements on both quantity and price, in addition to electricity from own power plants. Historically, the price agreements have involved fixed prices, and it is not common in Norway to tie the electricity price to the price of aluminium. Trading in the spot market are done to secure a low price at the margin also when all contracted electricity is used. Plants sell

contracted electricity at the spot market during winter time when price is high, and buy at summer time when price is low.

- The capital measure (K_f) reflects potential output, and may be interpreted as an efficiency-corrected capital measure, cf. Sato (1975, pp. 6-7). Changes in K_f may be due to (i) investments in capital with «old» technology, (ii) investments in capital with «new» technology (embodied technical change), or (iii) increased efficiency of existing capital (disembodied technical change). This implies that the coefficient γ_{KT}, which is assumed to capture changes in capital efficiency over time, should equal zero. Because capacity expansions are largely due to investment decisions and installations in previous periods, we assume the weak exogeneity assumption to hold and do not lag the capacity data when estimating.

A detailed discussion of the data is available from the author upon request.

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