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Oligopoly Pricing with Capacity Constraints

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ABSTRACT. – The shape of short run marginal cost (SRMC) is critical to understanding pricing behavior over the business cycle. We construct an econometric model of output and price determination for an industry with steep SRMC around capacity. In the North American aluminum industry, the capacity constraint plays an important role in pricing. When it binds, prices are high over a broad range of industry concentration. Market power raised prices at the cyclical trough much more when the industry was concentrated than it does now.

Fixation des prix par un oligopole sous contraintes de capacité

RÉSUMÉ. – La forme du coût marginal à court terme (CMCT) est essentielle pour la compréhension du mouvement des prix au cours du cycle conjoncturel. Nous construisons un modèle économétrique de détermination de la production et des prix pour une industrie dont le CMCT varie fortement près de la capacité. Dans le secteur de l'aluminium, en Amérique du Nord, la contrainte de capacité joue un rôle important dans la détermination des prix. Quand cette contrainte est serrée, les prix sont hauts pour un large domaine de concentrations dans le secteur. Le pouvoir de marché accroissait les prix au creux du cycle bien davantage quand l'industrie était concentrée que maintenant.

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1 Introduction

The issue of oligopoly pricing over the business cycle has engaged economists' attention for over half a century. [1] Prices might, because of market power, fall too little in periods of low demand. As a result, quantity produced and employment might fall too much. Empirical research on this topic, while suggestive, has not yet made clear that there is "too little" response in prices, because it has not been based on analysis in which the "right" response to demand falls is clear. The socially correct price response is clearly based on short-run marginal cost; much of the problem with prior research stems from an implicit assumption that SRMC is flat. [2]

In this paper, we account carefully for the nonflat SRMC caused by a sometimes binding capacity constraint. We first provide an analytical treatment of what market-power models predict about pricing in an industry with capacity fixed in the short run. We then construct an econometric model of output, factor demand, and price for such an industry and apply it in a detailed study of the North American aluminum industry. This involves two advances in method. First, we show how to effectively integrate firms' data on operations (as opposed to their accounting data) into models of cost. [3] As a result, our models have much more of an operations research flavor, rather than a smoothly substitutable neoclassical flavor. Second, we integrate the theory of market power into the econometric model of pricing, following the recent successes of the "New Empirical Industrial Organization". [4]

In our paper "Short-Run Supply with Capacity Constraints" the focus is on equations determining industry production and shipments in the short run. To an excellent first approximation, SRMC is linear out to capacity and vertical at capacity. By embedding that simple technical story into an econometric model of industry supply, we show that there exist two distinct regimes in the aluminum industry with desired quantity upper truncated by an unbending plant capacity constraint. Estimates for the sales equations also show switches between the two regimes. Thus, there is a marked right-angle SRMC influence on supply.

The next step is to take this two-regime result as given and study the industry's pricing behavior with respect to two separate variables. First, how does pricing during capacity unconstrained periods differ from pricing in constrained periods? This question addresses the issue of "sticky prices" over the business cycle in capital intensive, concentrated

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[1] HALL and HITCH [1939]; SWEEZY [1939].

[2] GODLEY and NORDHAUS [1972], DOMOWITZ *et al.* [1986].

[3] In this we follow Godley and Nordhaus, who provide a detailed treatment of average cost, but who do not use capacity or other data to analyze the gap between average and marginal cost.

[4] See BRESNAHAN and SCHMALENSEE [1987].

industries. Second, the decline in concentration that has taken place in the aluminum industry over the last few decades allows us to look at the issue of rigid prices under varying degrees of market power.

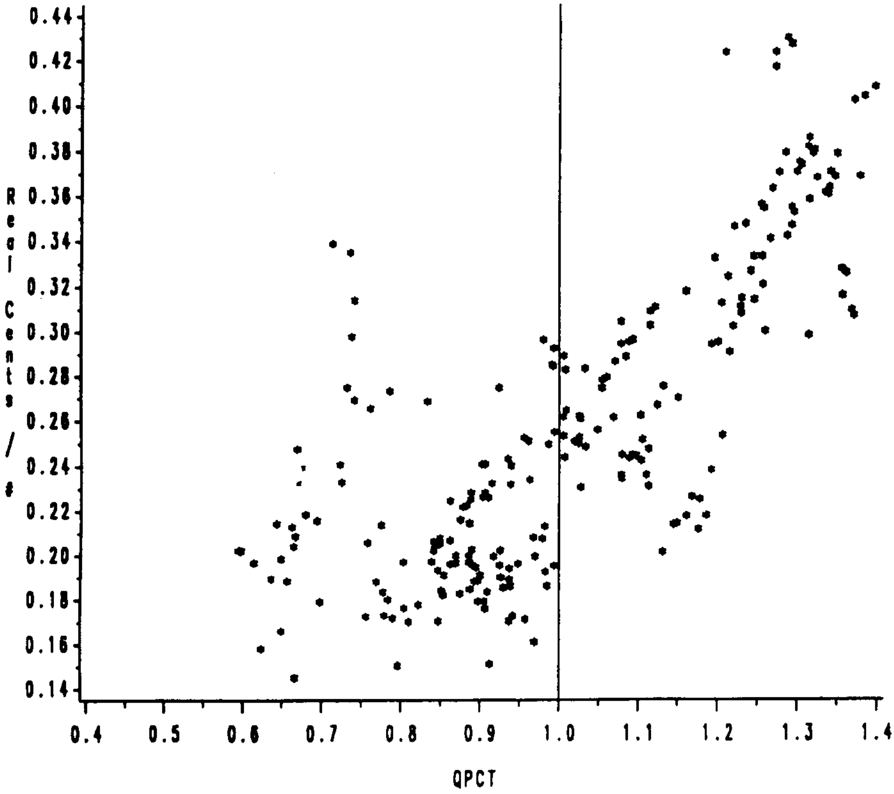

FIGURE 1

Supply Conditions and Price.

Figure 1 shows a plot of predicted prices over both regimes (the sample period is monthly data over 1957-1983). The horizontal axis is desired production divided by estimated capacity, labeled as QPCT. When QPCT is less than one there is excess capacity, when it is greater than one desired production is limited by the capacity constraint. The encouraging news is that the plot is somewhat upward-sloping, so that price is procyclical. On the other hand, there is no clearly observable regime shift. Further, the variation of price given QPCT is quite large. Figure 1 suggests an interesting puzzle; what forces lie behind this pattern of prices and quantities?

In this paper we attempt to shed some light on the puzzle. By adding a price equation and labor demand equation to the switching-regressions model (previously just determining quantity) our goal is to better understand the nature of pricing over trough and peak periods. The oligopolistic nature of the industry turns out to be an important clue to the puzzle.

2 Theory of Supply with Linear-Program Cost

In this section we focus on the supply problem of an industry whose SR behavior with respect to production is as shown in Figure 2. The figure

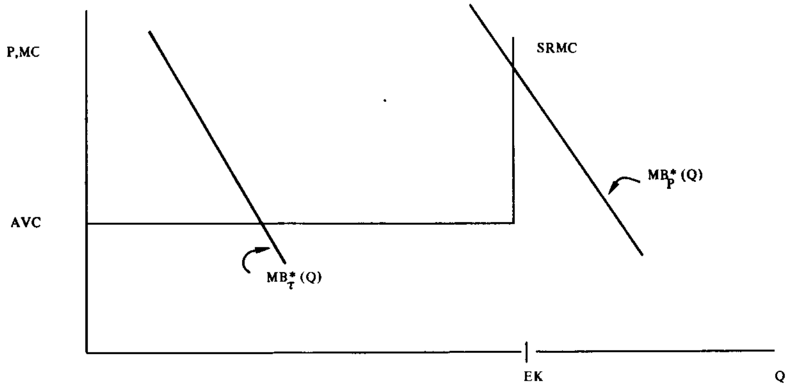

FIGURE 2

SRMC and Private Value: Quantity Determination.

depicts a short-run marginal cost (SRMC) function appropriate for some capital-intensive, flow-process industries, including aluminum. The definition of "SR" in SRMC is the run in which one can take as fixed both the height of average variable cost (AVC), determined by the level of technology, and the level of economically available capacity (EK), determined by the amount and type of plant and equipment. Our approach will take capacity, factor prices, and technology to be econometrically exogenous in monthly data. Further, we take capital to be completely fixed, and all other factors to be completely variable.[5] In the short run, AVC is thus given by the input requirements for variable factors.

Figure 2 also shows a downward-sloping function, MB(Q). This is the marginal benefit to the industry from production; for example, a collusive oligopoly would have MB(Q) = marginal revenue, a perfectly competitive one would have MB(Q) = demand. Actual production is determined by the intersection of MB and SRMC. It is useful, however to think of this in two stages. First, as the figure does, extend AVC past capacity. Then define Q_1^* to be the intersection of MB and AVC. The interpretation of Q_1^* is as "desired" production ignoring the capacity constraint. When $Q_1^* \geqslant EK$, the industry produces at capacity, when $Q_1^* < EK$, $Q = Q_1^*$. In our vision of SRMC the price of capital never enters SRMC directly. At the peak, the height of MC is determined by the shadow value of the constraint implied by not having more capacity; at the trough, capital's contribution to MC is zero. In fact, the larger is $Q_1^* - EK$, the larger is capital's contribution to SRMC. Considering the simple non-linear program

$$(1) \qquad \max \int_0^Q MB(\tau)\,d\tau - AVC.Q, \qquad \text{s.t. } Q \leqslant EK$$

shows this. If MB(Q) is a line, as in the figure, the shadow value of the constraint is proportioned to $Q_1^* - EK$ when the constraint binds.

In thinking about the downward-sloping curve in Figure 1, we will need to be robust to several different considerations. The first is production of a good that is potentially storable. The ability to hold output inventory drives a wedge between production and shipments in any given period. Thus, short-run supply describes both the selection of quantity produced (Q) and quantity shipped (S). We also need to be aware of the possibility that demand is linked over time, either because of the durable nature of the good or due to strategic interaction among firms. In either case expectations will matter and perceived marginal revenue (what the industry acts as if it sets equal to marginal cost) can become a function of present, past and future variables. The third issue is market power.

There are three fundamental endogenous variables in this setting: price, quantity produced, and quantity sold. Just reading the figure, we see that the equilibrium condition for the industry during its capacity unconstrained periods takes the general form:

$$(2) \qquad SRMC(Q) = MB(Q, S, P),$$

where MB is an unspecified marginal benefit function. We will not attempt to put an interpretation on MB(Q, S, P) in (2) that would permit much in

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[5] This assumption works rather better for aluminum, which appears to engage in no labor hoarding, than for many industries. When aluminum plants are not producing, they are staffed only by skeleton crews that maintain the capital equipment. Restarting production involves bringing back the crews. (Conversation with Mr. Jim Whitchurch, Manager, Operations Analysis. Alcoa Smelting Division.)

the way of inferences about market power, dynamics, etc. Nor will we explicitly model the aggregation of firms to the industry that lies behind (2). Instead, we will emphasize the implications of a general, unstructured form of equation (2) when confronted with right-angle SRMC.

The first step is solve out S and P in equation (2) so that the reduced-form for Q is revealed. BRESNAHAN and SUSLOW [1988] illustrate this for the cases of competition and monopoly. Oligopoly forms of behavior can be written in the form $SRMC(\cdot)=PMR(\cdot)$, where marginal cost equals perceived marginal revenue.[6] We will repeat the competitive case here.

The structural system with $MB(\cdot)=P$ is

$$SRMC(Q, W)=P \tag{3}$$

$$P=D^{-1}(Q, Y), \tag{4}$$

where W is a vector of cost factors in AVC and Y is a vector of demand side exogenous variables. Thus $MB^*(\cdot)$, the equilibrium MB, is $D^{-1}(Q, Y)$, and the reduced form equation for desired production is:

$$SRMC(Q_1^*, W)=D^{-1}(Q_1^*, Y), \tag{5}$$

$$\Rightarrow \quad Q_1^*=Q_1^*(W, Y). \tag{6}$$

This defines the reduced-form equation for the capacity unconstrained regime. When the capacity constraint binds, production is determined by the level of economically available capacity, EK (measured with some error which we will describe in detail in the next section).

If we let $X=(W, Y)$ and β_1 be unknown parameters, this leads to a two-regime model:

$$\text{Regime 1}: Q_1^*=X\beta_1 \tag{7}$$

$$\text{Regime 2}: Q^c=EK_2 \tag{8}$$

and

$$Q=\min[Q_1^*, Q^c], \tag{9}$$

where Q_1^* is the intersection of $MB(\cdot)$ and AVC in Figure 2, and Q^c is the quantity produced when the capacity constraint is binding.

Similarly, we can define price equations for each regime. They will take the form:

$$P_i^*=X\Gamma_i. \tag{10}$$

The price equations vary across regime first because marginal cost is a different function; capital makes a contribution in regime 2. But we also

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[6] This introduces an aggregation problem if industry behavior is not symmetric, for example if the capacity constraint binds tightly for some firms while it does not bind at all for others. This phenomenon is probably quantitatively unimportant for a technologically mature, stable oligopoly like Aluminum. It would be much more troubling in a context where different firms used different technologies.

expect the role of market power to vary between regimes. In Figure 4, we show demand and marginal revenue. At D_T, MR_T, the monopolist and competitive industry charge very different prices. Thus market power has an effect in the trough. At D_p, MR_p, the monopolist and competitive industry behave identically, thus market power is much less important at the peak. For oligopoly, the appropriate theory is intermediate. The oligopoly PMR will fall in between D and MR. Thus the degree of price fall at the trough is determined by the extent of competition. The price at the peak, however, is not affected by the extent of competition.

We turn now to an empirical analysis of the determination of price in the aluminum industry. The next section lays out the relevant institutional details for the industry. We will use this information to determine the specifications for the quantity, price, and labor demand equations.

3 Aluminum Industry Particulars

This section focuses on the details of the production process in the primary aluminum industry (SIC #3334). We also discuss competition and market definition issues in this section, and comment on the definitions of some key variables. Table 1 gives brief definitions and means eof variables referred to in the text.

By all accounts, aluminum smelting in any particular plant at any particular time takes place according to a fixed-coefficients production function, in which alumina is reduced to crude aluminum by means of an electric current.[7] Nonmaterials inputs include capital, an important component of which consists of electrolytic "pots" organized into "potlines" in "potrooms" in the now thirty-two primary aluminum plants in North America. Production workers' hours are dependent on the operation of the potline and on the making of anodes for the pots. When it is in operation, a line runs 24 hours a day, seven days a week, using 4 crews working 21 shifts. Potlines are the basic unit of production supply; they are switched on and off with some frequency, although at a cost.[8] Production is thus highly divisible and total variable costs (in a particular plant at a particular time) are proportional to the number of potlines in operation and thus to output.[9]

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[7] STUCKEY [1983], pp. 16-17.

[8] Minimum maintenance is needed when pots are shut down. The power costs of remelting the "bath", the possibility of cracked pot lining, and the labor costs of avoiding cracked linings are the primary restart costs. Mr. Whitchurch of Alcoa estimated these at 1-1.5¢/1 b. of capacity.

[9] The typical plant layout involves one or more potrooms and a carbon anode assembly facility, with 1 or 2 potlines per potroom and 100-250 pots per potline.

The industry has seen some labor-saving technical change over the period, which can be characterized into two broad movements. First was the burst of new capacity and increase in average plant size by roughly one-third in the 1950's. This first movement represents a period of embodied technical change: new equipment was installed and plants built before World War II were retrofitted. The second major advance was the automation of all potroom operations in the late 1960's and early 1970's. The extensive use of mechanization boosted labor productivity significantly.[10] Accordingly, we include not only the real wage rate,[11] but also the real wage rate interacted with three technology variables. These are: $T_{1t} = K_t$ for observations through 1961, $T_{1t} = K_{1961}$ at later times, where K is installed industry capacity. $T_2 = \text{YEAR} + (\text{MONTH-1})/12$ is a time trend designed to capture autonomous technical change, where $\text{YEAR} = 58, \ldots, 83$ and $\text{MONTH} = 1, \ldots, 12$. T_3 accounts for the diffusion of automation through the industry; it is a time trend that begins in 1967.

The short-run labor demand equations L_1^* and L_2^* are specified based on this detailed investigation of aluminum technology. Bringing twice as many potlines into production produces very nearly exactly twice as much aluminum and requires very nearly exactly twice as much blue-collar labor. Thus, in our preferred specification we model L as proportional to Q in each regime:

$$L_i^* = Q(\delta_0 + \delta_1 T_1 + \delta_2 T_2 + \delta_3 T_3) + e. \tag{11}$$

In early experimentation, we discovered that the δ's from regime 1 and regime 2 were very similar, and that the variances of the labor-demand equation in the two regimes were also very close. Therefore, we impose a single labor demand equation, independent of regime, as an identity.

The second departure from proportionality occurs when potlines are being restarted after a shutdown. A crew can work as long as two weeks before metal is produced. To capture this, we included $\max(0, Q_{t+1} - Q_t)$ as a regressor in (11). This variable *did* get a coefficient of about .5 in the regression, but it's standard error was over two. We report results without the variable below; results with it are very nearly identical.

Our industry sources did not report any other dynamic labor demand practices.

Our industry sources similarly reported that energy and materials were used in fixed proportion to output. Energy's contribution to marginal cost *might* exceed its contribution to average costs. This would happen when, taking advantage of the "interruptible" contracts they have with aluminum producers, electric utilities sold then less than their desired quantity of power. We treat this as a capacity constraint.

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[10] See the Bureau of Labor Statistics publication "Technological Change and Manpower Trends in Six Industries", *BLS Bulletin*, 1817, 1974.

[11] Throughout, "real" means "deflated by the PPI".

Several variables that shift AVC enter X. A chronology of standard hourly wages for Alcoa has been kept by the BLS since the 1930's. Data are provided by plant, union, and job grade.[12] Our real wage series is based on the average job grade and is a weighted average across membership in two unions. Cost-of-living adjustments are added to the wage series based on formulas prescribed in the contracts.

Materials prices are based on Census data. As defined by the Census of Manufactures, "cost of materials" refers to direct charges actually paid for items consumed. It includes the cost of fuels consumed for heat, power, or generating electricity. Alumina accounts for the bulk of materials costs, and has been used in constant proportions to aluminum output since the aluminum refining process was invented in 1896. Such is not the case of electricity, where there have been major advances since 1974. Despite investment in electricity-saving production methods, the industry average electricity requirement has decreased very slowly.[13] Thus we do not estimate any materials-demand equations in the SR; instead we assume that material's contribution to SRMC is unit materials cost (defined as COM/Q, where COM is cost of materials from the Annual Survey of Manufacturers).[14]

The capacity figure in our data is monthly nameplate North American primary ingot capacity. Actual available or economic capacity may differ from nameplate capacity because of variations in the availability of electric power. In particular, major cuts in power allocations to aluminum producers were made by the Bonneville Power Authority several times between 1977 and 1980. As a result, we adjust K to reflect available capacity during these power brownouts. Our adjustment factor, BPA, is equal to Bonneville's operating rate multiplied by the fraction of aluminum capacity served by Bonneville (a constant over our sample of roughly thirty percent).

Aluminum is like other "smokestack" industries in that there has been a tremendous increase in competition over the sample period. However, it is atypical in that the source of this competition has largely come from domestic entry rather than imports, due to tariff protection and high shipping costs.[15] In 1957 the annual average market share held by imports (to the U.S.) was roughly 10%. By 1982 it had grown only to 13.9%. The bulk of this imported aluminum ingot comes from Canada, and in particular

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[12] Two unions, the United Steelworkers of America and the Aluminum Workers International Union, organize Alcoa's plants and have historically negotiated contracts at the same time. The wage structure set at Alcoa has been followed by the other major firms in the industry. An average of 15 job grades existed over the sample period.

[13] *Minerals Yearbook* states that the sum of all technology improvements from 1960 to 1980 decreased electricity usage from 7.7 kilowatt-hours (kwh) per pound to 5.9 kwh per pound in modern plants (*Minerals Yearbook*, Vol. 1, 1981, p. 90).

[14] Since aluminum plants are large, the ASM has complete coverage even in intercensal years. We interpolate the annual unit materials cost figures to get monthly costs.

[15] Ingot carries a tariff of one cent per pound and accounts for most of the imports, versus aluminum shapes, with tariffs of 3.5 to 5 cents per pound (9.5% of value). A 1976 Council on Wage and Price Stability publication on aluminum (hereafter referred to as COWPS) reports that shipping costs from Japan and Europe to the American market average about one-fifth the price.

from Alcan, which has accounted for roughly 85% of Canadian capacity for the entire sample period.[16]

Concentration in the North American market, as in the world, has been steadily declining over time. Let H be the Herfindahl index measured in capacities, over three possible market definitions: the U.S., North America (the big three U.S. producers plus Alcan), and the world. As Table 2 shows, concentration in the narrower markets starts very high and declines to a middling level, while world concentration declines in parallel. Within North America, the cause of this decline has been the expansion of small fringe firms following the government subsidized entry of Reynolds and Kaiser after World War II.

In 1950, the U.S. aluminum industry consisted of Alcoa, with 49% of the primary aluminum market, Reynolds (at 32%), and Kaiser (at 19%). By 1965 six fringe firms accounted for roughly 16% of the market, and only five years later in 1970 the size of the fringe doubled to roughly 30% (10 firms). Since 1970 the fringe has grown slowly, amounting to 38.5% of the market in 1983, but this growth has kept pace with (and at times surpassed) the growth of the top firms. Over the entire sample period the U.S. Herfindahl has fallen from .33 to .13 as Table 2 shows. Alcoa has maintained its dominance among the "Big Three" firms. Its primary aluminum market share has been constant at 31.4% since 1970, while Reynolds and Kaiser's combined share has fallen from roughly 50% in 1965 to 30% in 1983.

In Canada the story is much simpler. As noted above, Alcan has dominated the industry throughout the sample period. Only one other small firm has existed, which since 1969 has been owned by Reynolds. The Herfindahl index defined over the North American market follows the same pattern as the U.S. index, declining from .27 to .11 over the sample. Thus, the source of increased competition in the industry has come from an ever expanding fringe as well as a growing imbalance of power at the top of the industry since its restructuring after World War II.

This is not to say that we are convinced that North America is isolated from world markets for aluminum. Rather, for our purposes in this paper, there is little distinction between a North American market approach and a world market approach.

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[16] Other major exporters to the U.S. are Ghana, Norway, and Japan. Imports from the first two countries pose no threat since the capacity in those countries is owned by U.S. producers. Imports from Norway have declined dramatically since 1970 when the aluminum smelters were nationalized. Prior to 1970 the smelter capacity was owned by U.S. producers (see COWPS, p. 44). For Japan, the barrier is high production costs. In 1974 Japan had estimated average costs of producing primary aluminum that were fifty percent higher than North American producers (COWPS, p. 42).

Data

Our sample period runs from 1958-1983, but is pared down from 312 to 215 monthly observations for the following three reasons. First, from 1958-1963 our sample includes only the first three months of each year.[17] Second, a strike during the summer of 1968 led us to delete 1967-1968 from the sample, based on the high productions levels and inventory buildup which preceeded the strike.[18] Finally, January 1973 through July 1974 are omitted due to the price controls.[19]

The aluminum industry data were compiled primarily from five sources: *American Bureau of Metal Statistics Yearbook*, *Aluminum Statistical Review*, *Metals Statistics*, *Metal Bulletin Handbook*, and *Mineral Industry Survey*. Additional data came from the *Census of Manufactures*, and the BLS *Employment and Earnings*. Specific sources for individual variables are given in Appendix A.

The sample period runs from January 1958 through December 1983.[20] When possible the data are monthly, for example, aluminum prices, production, shipments, and inventories. Important variables available only on an annual basis are production capacity and materials costs. Monthly information related to these annual variables was used when possible. For instance, the Bureau of Mines publication, *Mineral Industry Survey*, occasionally gives dates for major mid-year capacity expansions.

Shipments data includes all private domestic shipments of primary ingot plus the aluminum content of domestically shipped mill products. Imports and shipments of secondary aluminum are excluded. Our inventory series is created using an April, 1974 benchmark figure taken from *Current Industrial Reports*. This benchmark figure represents inventories of ingot and mill products at the sites of integrated, non-integrated, and secondary producers. Inventories are not easily calculable from production and shipments data, because of incomplete coverage of the industry.[21] The data for production, nameplate capacity, unit sales, and inventories all have units 100,000 tons.

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17. This is due to a data constraint on total production worker hours for the aluminum industry.
18. The actual strike lasted only two months. But supply behavior in the months preceeding the strike was affected by anticipation of it.
19. See footnote 27 of BRESNAHAN and SUSLOW [1988].
20. The early 1950's were eliminated due to the Korean War. Also in the early 1950's the U.S. government instituted a subsidized expansion program for the aluminum industry. Contracts were written in 1950-1952 and expired in 1958 for the big three producers. By 1958 all of the new capacity built with government aid had come on-stream.
21. Conversation with Ed Coan, Industry Division, Bureau of the Census, May 1987. Data are missing on the quantities of new scrap that flow through the system (for example, from the fabricators of aluminum shapes back to the primary producers). In fact, the inventory data we use from *Current Industrial Reports* are not calculated from production and shipments data within that report, but are reported as a separate line item by aluminum producers.

TABLE 1

Brief Variable Definitions and Means.

Variable	Definition	Units	Mean	Standard deviation
Month	—	1, . . ., 12	6.21	3.56
Year	—	58, . . ., 83	73.09	6.98
Q	primary alum. production	100,000 tons	3.20	.81
K	primary alum. capacity	100,000 tons	3.70	.91
K* BPA . . .	capacity times electricity shortage	fraction	.111	.321
RWAGE . . .	avg std hourly rate plus COLA, aluminum production workers	index	0.43	.321
RMATS . . .	cost of materials	index	0.28	.04
RPRICE . . .	real primary alum. price	1967 cents/lb	23.6	4.1
LEAD	index of 12 leading indicators	1967 = 1	1.20	.24
IPDTTB . . .	index of trucks and buses	1977 = 1	0.59	.25
IPDT2	index of motor vehicles & parts	1977 = 1	0.72	.17
IP372	index of aircraft and parts	1977 = 1	1.20	.18
HSBP	index of new pvt. housing	1967 = 1	1.17	.33
PW	PPI, all commodities	1977 = 1	1.74	.76
TIME	–	((year-57)*(12) + month)/120	1.63	.69
NAHERF . .	Herfindahl index for North America	HHI	.154	.023
INVR	Primary aluminum Inventories	100,000 tons	.229	.070
L	Hours worked	1,000	4365	989

The price series we use from 1970 to the end of the sample comes from *Metals Week's* estimate of the "market price" of aluminum. They obtain their estimate by collecting data on a sample of trades made by producers, consumers, and traders for prompt (deliverable in the next 30 days) Midwest metal [22]. Significant list/transactions price differences occurred during the 1970-1971 and 1981 downturns and the 1974 oil price shock. From 1958-1969 the only primary aluminum price series available represents monthly averages of 99% + virgin ingot aluminum: these are list prices. [23] There *are* excellent transactions prices for scrap aluminum for the entire period. Though scrap is slightly cheaper than new aluminum, its price is very nearly perfectly correlated with the transactions price for new metal in

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22. Telephone conversation with Ken Jacobson, Aluminum Editor at *Metals Week*, April 1987.
23. In 1970 the Bureau of Labor Statistics shifted slightly from a "seller's price" approach to a "buyer's price" approach, on excellent evidence that the prices they had been collecting from sellers were basically list prices. See COWPS for a detailed treatment.

those years when we observe both.[24] Accordingly, we interpolated the price of new aluminum using the scrap price for the period before 1970.[25]

4 Estimation and Testing

We first write equations (2) and (4) in econometric form, and add equations for the other dependent variables.

Regime 1:

(12) $$Q_1^* = X\beta_1 + E_1$$

(13) $$P_1^* = X\Gamma_1 + E_2$$

(14) $$L_1^* = X\Delta_1 + E_3.$$

Regime 2:

(15) $$EK_2 = X\beta_2 + E_4$$

(16) $$P_2^* = X\Gamma_2 + E_5$$

(17) $$L_2^* = X\Delta_2 + E_6.$$

Switching Condition:

(18) Regime 1 holds if and only if $Q_1^* < EK_2$.

We assume that E_1, E_2, E_3 are joint normal, and that E_4, E_5, E_6 are joint normal, but that the two sets of errors are (groupwise) independent of each other.

The shape and the distribution of the error in the capacity equation is uncertain. Previous tests in BRESNAHAN and SUSLOW [1988] have shown that a normal distribution is a reasonable assumption.

Below, we will describe the specification of the six functions $X\beta_1, \ldots, X\Delta_2$. There are some important cross-equation restrictions and

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[24] This is particular to the period we study. SUSLOW [1986] found that new and recycled aluminum were imperfect substitutes in demand in an earlier era.

[25] Precisely, we regressed the real price of new metal, taken from *Metals Week*, on the real scrap price, "Monthly average dealer's buying prices for cast aluminum scrap" for 1970-1983. We then simulated the regression in the earlier period.

many exclusion restrictions. It is convenient to describe the likelihood function in this compact notation, however, and we shall do this first.

Let the variance-covariance matrix for E_1, E_2, E_3 be Σ_1, and that for E_3, E_4, E_5 be Σ_2. Further, let the variance of E_1 be σ^2_{1Q}, that of E_4 be σ^2_{2Q}: these are the upper-left elements of Σ_1 and Σ_2, respectively. Write the trivariate normal density function for regimes 1 and 2:

$$f_1 \equiv \varnothing((Q-X\beta_1,\ P-X\Gamma_1,\ L-X\Delta_1)',\ \Sigma_1) \tag{19}$$

$$f_2 \equiv \varnothing((Q-X\beta_2,\ P-X\Gamma_2,\ L-X\Delta_2)',\ \Sigma_2). \tag{20}$$

Then the likelihood for a particular observation is

$$\mathscr{L} = \left(1-\Phi\left(\frac{Q-X\beta_2}{\sigma_{2Q}}\right)\right) \cdot f_1 + \left(1-\Phi\left(\frac{Q-X\beta_1}{\sigma_{1Q}}\right)\right) f_2, \tag{21}$$

the usual expression for disequilibrium models with independence across regimes. (See MADDALA [1984] and QUANDT [1988].)

Specification of Predicted Values

Our specification of $X\beta_1$ closely follows BRESNAHAN and SUSLOW [1988]. $X\beta_1$ contains thirteen variables, of which six obviously are cost shifters, 4 obviously are demand shifters, and the rest are ambiguous. The exact list of variables can be seen in Table 2; it differs from our earlier paper only in that the level of inventories has been added.

TABLE 2

Market Shares (Primary Capacity) for Top Producers (%).

	U.S.			North America			World		
	1957	1970	1982	1957	1970	1982	1955	1971	1979
Alcoa	43.1	31.4	28.5	29.8	24.5	22.9	20.4	17.1	15.1
Reynolds	26.6	22.4	17.6	18.4	17.5	14.1	15.0	11.8	8.8
Kaiser	27.1	16.8	13.1	18.7	13.1	10.5	14.6	8.4	7.8
Alcan	–	–	–	29.1	18.9	17.2	26.2	19.9	16.3
Pechiney	–	–	–	–	–	–	5.8	10.0	8.3
Alusuisse	–	–	–	–	–	–	3.9	5.8	5.9
C*	96.8	70.6	59.2	96.0	74.0	64.7	85.9	73.0	62.2
H*	.33	.18	.13	.24	.14	.11	.16	.10	.07

* C = n-firm conc. ratio, H = n-firm Herf. Index, where $n = 3$, 4, or 6. Sources: Domestic figures from *Aluminum Statistical Review*, Minerals Yearbook. World figures from STUCKEY [1983], p. 84.

Our specification of $X\beta_2$ again follows our earlier paper; available capacity is modelled as a function of rated capacity K and of electricity shortages in the Pacific Northwest, BPA. The estimated coefficients of $X\beta_1$ and $X\beta_2$ reported below also closely resemble those in our earlier paper, and we will have little to say about them.

Specification of the price equation in each regime follows recent practice in empirical Industrial Organization (see BRESNAHAN [1988]). In each regime, we write

$$P_i^* = MC_i + \text{Markup}_i. \tag{22}$$

In regime 1, our initial and preferred treatment of MC is straightforward. We write

$$MC_1 = RUMC + RWAGE\,(\delta_0 + \delta_1 T_1 + \delta_2 T_2 + \delta_3 T_3) \tag{23}$$

where RUMC is real unit materials costs, RWAGE is the real wage, and the function in parenthesis is the derivative of SR labor demand with respect to quantity. Thus we are imposing the restrictions implied by duality theory. In this specification, SRMC in regime 1 is a constant with respect to quantity, consisting of the sum of unit materials costs and unit labor costs. We will report some experiments with this specification below; we begin with it because it is suggested by the industry sources.

In regime 2, the specification of marginal cost is somewhat more complex. To understand our initial specification, return to Figure 2 briefly. In that figure, capital makes a contribution to marginal cost when $Q_1^* > EK$. The larger is the excess of desired production over capacity, the greater is the pressure on capacity and, correspondingly, the larger capital's contribution to marginal cost. We make a linear approximation to this, and our first specification for regime $-$ 2 MC is

$$MC_2 = RUMC + RWAGE\,(\delta_0 + \delta_1 T_1 + \delta_2 T_2 + \delta_3 T_3) + \gamma_0 (Q_1^* - EK). \tag{24}$$

Since Q_1^* is a function of exogenous variables only, this raises no simultaneity issue.

The proliferation of oligopoly theories implies that there is somewhat less guidance regarding the shape of the specification of the markup term. Since most oligopoly theories, cooperative or not, suggest that less concentrated industries will more easily achieve anticompetitive outcomes, we include a measure of concentration in each regime. As our market discussion above suggested, we use the HHI for North America. Most oligopoly theories also suggest a term in the size of demand, and we use Q_1^* in both regimes. The theory behind Figure 2, of course, suggests a much smaller role for the markup term in regime 2.

Though we have estimated several closely related specifications, for reasons of brevity we will discuss only our preferred specification in detail. The estimates for that specification are presented in Table 3.

The quantity-setting side of the model exhibits simple behavior over time. (We described it in somewhat more detail in BRESNAHAN and SUSLOW [1988].) The time series EK grows slowly after the early sample period; even in severe power shortages, EK shrinks only a small amount. The "desired" production series Q_1^* is much more volatile. It falls well below EK in recessions, and goes well above it in booms. These two time series of predicted values are graphed in Figure 3, along with actual Q. As you can see, MIN $[Q_1^*, EK]$ is a very good predictor of Q.

TABLE 3

Var	Coef	Std. Error
Q_1^* Equation		
ONE	−1.465	1.331
LEAD	2.194	0.464
RWAGE	−88.241	32.415
RMATS	0.971	2.212
WT1	53.089	23.044
WT2	13.762	2.171
WT3	7.148	2.431
HSBP	−0.571	0.140
IPDTTB	0.266	0.163
IP372	1.386	0.257
TIME	4.327	0.570
TIMESQ	−5.058	2.301
NAHERF	−6.005	3.913
INV	−11.965	1.254
EK Equation		
KR	95.667	0.409
KRBPA	−0.281	0.038
SR Labor Demand		
LPROD-1	14.604	0.436
T1	−26.389	5.048
T2	−1.436	0.664
T3	−0.221	0.092
P_1^* Equation		
P1-ONE	−0.235	2.670
NAHERF	64.493	18.486
Q_1^*-EK	8.143	0.565
P_1^* Equation		
P2-ONE	9.074	0.387
Q*-EK	-24.057	12.557
(Q*-EK) I	4.234	1.984
Variances		
SIGP1	0.656	0.100
SIGP2	0.639	0.111
SIGPQ1	−0.026	0.021
SIGPQ2	0.029	0.019
SIGMALAB	0.757	0.062
SIGQ1 | P1	−1.805	0.081
SIGQ2 | P2	−2.385	0.115

Given this behavior of predicted quantities, it is sensible to describe regime 2 ($Q_1^* > EK$) periods as the cyclical peak, and we adapt this convention. Regime 2 occurs primarily because demand in the short run outstrips available capacity, which is set long in advance.

The first clear finding in Table 3 is that prices are substantially higher in the cyclical peak. Hold the supply-side variables (input prices, $T_1 - T_3$, K and concentration) constant at their means. Let the demand-side variables in Q_1^* take on two sets of values. The first set implies $Q_1^* - EK = -.8$, the mean conditional on regime 1. The second set implies $Q_1^* - EK = -.5$, the mean conditional on regime 2. Then simulate the system reported in Table 3. This leads to the following results

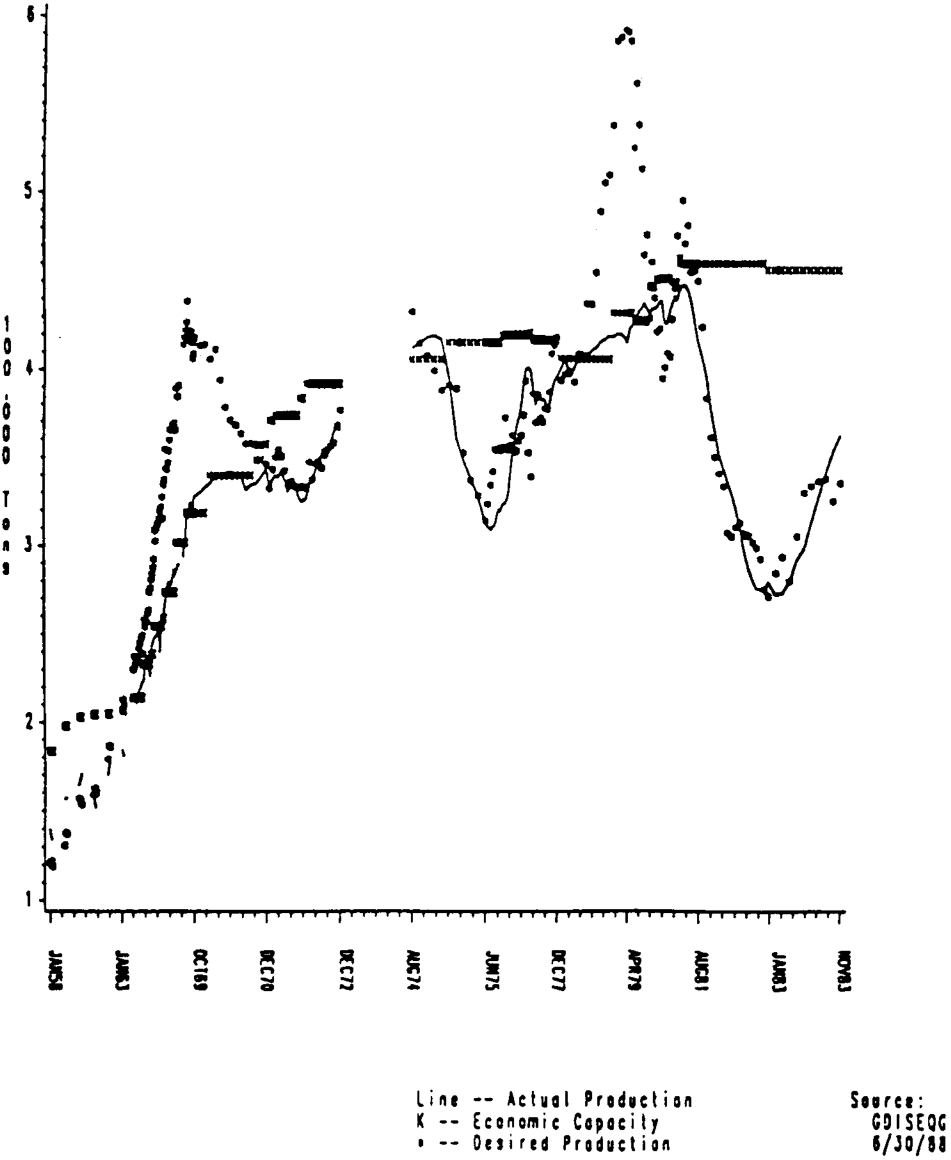

FIGURE 3

Production, Q, and K.*

$Q_1^* - EK$	P_r (regime 1)	E[P]
−.8	.999	22.14
.5	.000	25.14

As you can see, regime 2 (cyclical peak) prices are somewhat higher. This difference is enchanced when we consider P − AVC at the same points. The mean of AVC conditional in regime 1 is 17.28, the mean of AVC conditional on regime 2 is 16.20. Thus P-AVC at the trough averages 4.86; while P-AVC at the peak averages 8.94. Clearly, P-AVC is procyclical. A long but incorrect tradition refers to this as "procyclical margins". However, the procyclical P-AVC does *not* imply a procylical price-*marginal* cost margin. Some of the higher peak prices may be higher MC, as pressure on capacity contributes to MC there.

The second clear finding is that concentration only affects prices in the trough, and affects them strongly there. Indeed, in the reported results, P_2^* does not depend on NAHERF. (When we let NAHERF go free in regime 2, it gets a coefficient of −8 with a standard error of 19.) The effect on P_1^* is quite strong. At the least concentrated point in our sample, P-AVC at the trough is predicted to be 3.25. At the most concentrated point, P-AVC is predicted for the trough at 9.57. Thus we see that the increase in concentration over time is related to a charged pricing relationship at the cyclical trough. In the early going, the highly concentrated industry has very substantial P-AVC. In the late going, prices fall much closer to AVC.

No effect of concentration is seen at the peak. Of course, this is exactly as the theory predicts; A vertical supply curve renders market power largely irrelevant. (Note that the other standard theoretical prediction that the more concentrated/greater market power industry will hit the capacity constraint only for a larger demand curve, is also borne out in Table 3.) The two predictions do diverge to the left of the capacity constraint; prices fall much farther in a trough at the lower concentration level. (Quantity produced is also larger, for given demand-side parameters, at the lower concentration level.) What is driving these differences, of course, are the large and precisely estimated coefficients of NAHERF in P_1^* and Q_1^*.

The overall implications of this analysis for concentration and pricing are remarkably reminiscent of analyses from the 1930's. The market power permitted by industry concentration affects behavior at the cyclical trough, not at the peak. More concentrated industries have prices which fall less and quantities which fall more at the trough. We *do not* believe it is sensible to infer any particular form for market power, such as the hypermodern "kinked demand curve". As we explained above, almost any sensible market power theory has this implication.

It is clear from the theory (ies) underlying Figure 1 that marginal costs will be higher at the cyclical peak because of the pressure on capacity. Our models, however, are not sufficiently precise to say much about movements of MC within regime 2. The coefficients of interest are those of average variable cost, of $Q_1^* - EK$, which is proportional to the shadow value of capacity, and the regime-2 constant.

Small changes in our specification lead to considerable movements in the coefficients of each of these variables. The *total* effect of all three variables is always to imply substantially higher on-peak prices. We conclude that both price and marginal cost are higher at the peak, but that the model is not capable of saying whether P or MC rises faster as pressure on capacity grows. Perhaps this should not be too surprising; in regime 2, MC is nearly vertical. The model does a terrific job of predicting quantities, but cannot resolve prices well at all.

The price-marginal cost picture is considerably clearer when the capacity constraint does not bind. The positive coefficient of $Q_1^* - EK$ in P_1^* implies that price falls even farther in a deep trough than in a shallow one. One possible explanation of this is that marginal cost is upward sloping below capacity. Another possible set of explanations could have to do with market power. The instantaneous demand curve for aluminum could be flatter at the deep trough, as buyers have more opportunities to perform intertemporal arbitrage. Or the temptation of excess capacity could lead to more competitive conduct at the deep trough.

We can provide considerable evidence against the sloped-MC hypothesis and, by implication, for the class of hypotheses with nonconstant price-cost margins. The three hypotheses to be investigated are:

(*a*) UMC is rising in Q;

(*b*) ULC is rising in Q; and

(*c*) some marginal capital costs matter off peak, perhaps more so nearer capacity.

The nature of our data leads us to treat each of these slightly differently.

For UMC, we have one piece of qualitative evidence and one of quantitative evidence. The *industry* MC might well have slope because plants have heterogeneous costs. On the materials side, the plausible heterogeneity is in energy prices. Aluminum is electricity-intensive, and plants tend to be located near cheap, stable sources. Yet energy prices vary substantially across North America; if plants in high-cost locations were to shut down before plants in low-cost locations, this would be a slope to industry MC. There is however, excellent evidence that this is not what happens.[26]

The quantitative evidence is provided by a slightly alternative specification of MC_1. We rewrite (24) as

$$(25)\qquad MC_1 = \gamma' \, RUMC + RWAGE\,(\delta_0 + \delta_1 T_1 + \delta_2 T_2 + \delta_3 T_3)$$

so that RUMC need not have a coefficient of one. In this alternative specification, γ' is estimated at .96, with a standard error of .4. Thus, the data do not reject the notion that unit materials costs contribute one for one to marginal costs.

For labor, we observe monthly hours demanded. Thus we can test directly to see whether ULC is rising in Q_1^*. To do this, we run an auxiliary regression of the form

$$(26)\qquad L_t = Q_t(\gamma_0 + \gamma_1 T_1 + \gamma_2 T_2 + \gamma_3 T_3) + \gamma_4 Q_t^2 + h.$$

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[26] We examined the pattern of plant and potline closings from reports in *Mineral Industry Surveys*. The most common pattern is for some potlines at all plants, rather than all the potlines at some plants, to be shut down in a trough.

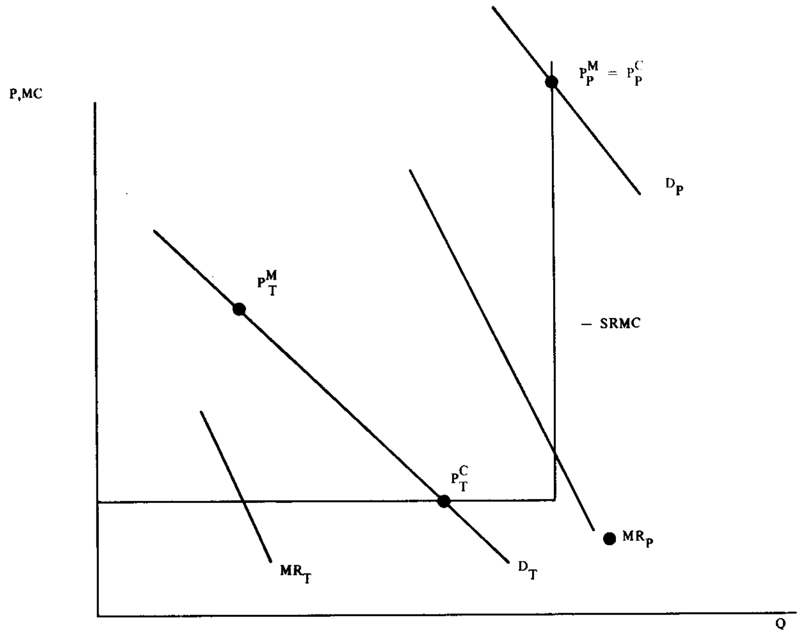


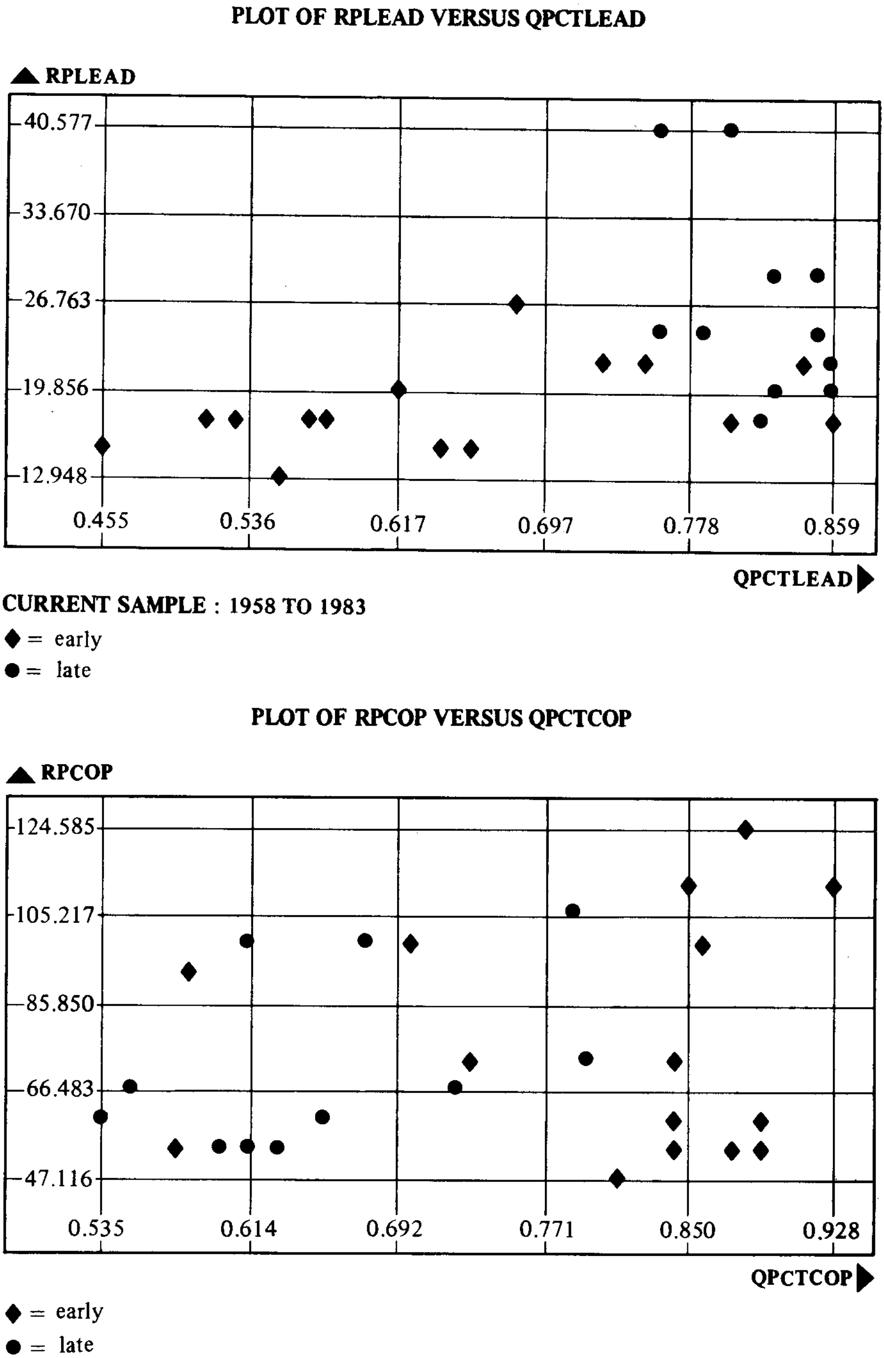
FIGURE 4

This leads to estimated γ_4 of zero. Replacing $\gamma_4 Q_t^2$ by $\gamma_4'(Q_1^* - EK)$ in the table does little to change the story.

Finally, for capital, we include an appropriate ex post real interest rate in both the P_1^* equation and the Q_1^* equation. In the P_1^* equation, we interact r with $Q_1^* - Ek$. We find that its coefficient is near zero.

It seems clear, therefore, that departures of the SR cost function from the form that industry sources describe are quantitatively unimportant. The industry SRMC is a right angle. Prices are above that SRMC at the cyclical trough particularly for the concentrated part of the sample.

Finally, the skeptic might think that there was some omitted demand or cost variable which caused these changes, for example some fundamental difference in the macroeconomy between our early and late sample period having nothing to do with Aluminum market power. Such an effect should be visible for other nonferrous metals as well. To check this, we considered Copper and Lead in the U.S. for some period. (See Figure 5). Neither


PLOT OF RPLEAD VERSUS QPCTLEAD

PLOT OF RPCOP VERSUS QPCTCOP

a) Plot of RPLEAD versus QPCTLEAD

b) Plot of RPCOP versus QPCTCOP.

of these industries has much time-series change in concentration, and economywide forces hit them similarly to aluminum.[27] The data for these graphs are annual, and based on Census information.

Figures 5*a* and *b* plot the annual real price against capacity utilization. For the copper plot, the volatility of price appears roughly constant over the "early" and "late" subsamples, in contrast to aluminum. Lead looks markedly different than aluminum when capacity utilization is high, but is similar in the later years in terms of increased volatility. There are enough differences to safely conclude that the phenomenon observed for aluminum is not simply produced by changes in metals demand.

5 Conclusion

Following a suggestion by Paul Geroski, we would like to turn our conclusions on their head, and think for a moment about the long-run dynamics of the aluminum industry. Before the second world war, North America primary aluminum was a stable monopoly. There was competition from a recycling fringe but it put only weak limits on Alcoa's monopoly power (SUSLOW [1986]). Between the end of the war and the beginning of our sample period, government antitrust policy created a tightly concentrated oligopoly, with four firms. Our estimates show that the tight oligopoly willed considerable market power in the cyclical trough. Over time, two more firms entered, and the smaller firms grew more rapidly than the large. With this decrease in concentration, pricing at the cyclical trough grew more competitive.

Turned on its head, this is the normal working of the competitive entry and capacity expansion process. The natural long run response to initial conditions with noncompetitive price is entry and the expansion of the fringe. These processes, in turn, tend to reduce the market power that led to them. Aluminum, with its long lead times to build new capacity and its very long-lived capital, saw these processes go very slowly, as the increase in competition we document in this paper took decades. In other contexts, competition's clock runs faster, and the flow of causation from pricing to entry is strong enough to measure.

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[27] Copper's C4, according to the Census of Manufacturers, averaged roughly 75% (beginning and ending at 87% with a low of 71% in 1966). Lead is highly concentrated throughout the period (a C4 of over 90%).

References

BAUMOL, W. J. (1961). – *Economic Theory and Operations Analysis*, Prentice-Hall.

BRESNAHAN, T. F. (1989). – "Empirical Studies of Industries with Market Power" forthcoming in R. SCHMALENSEE and R. WILLIG eds., *Handbook of Industrial Organization*, North Holland.

BRESNAHAN, T. F. and SUSLOW, V. Y. (1988). – "Short Run Supply with Capacity Constraints", Stanford University Studies in Industry Economics, forthcoming, *Journal of Law and Economics.*

BRESNAHAN, T. F., and SCHMALENSEE, R. (1987). – "The Empirical Renaissance in Industry Economics: an Overview", *Journal of Industrial Economics.*

CHARLES RIVER ASSOCIATES (1971). – *An Economic Analysis of the Aluminum Industry*, prepared for the General Services Administration, Washington, D.C.

CHRISTENSEN, L., and GREEN, W. (1970). – "Economies of Scale in the U.S. Electric Power Industry", *Journal of Political Economy*, pp. 655-680.

COUNCIL ON WAGE AND PRICE STABILITY, (1976). – *Aluminum Prices* 1974-1975, Staff Report, September.

DOMOWITZ, I., HUBBARD, R. G. and PETERSEN, B. C. (1986). – "Business Cycles and the Relationshiop between Concentration and Price-Cost Margins", *Rand Journal of Economics*, 17, pp. 1-17.

GODLEY, W. and NORDHAUS, W. (1972). – "Pricing in the Trade Cycle", *Economic Journal*, Vol. 82, September, pp. 853-882.

HALL, R. L. and HITCH, C. J. (1939). – "Price Theory and Business Behavior", *Oxford Economic Papers.*

KAPLAN, R. S. (1982). – *Advanced Management Accounting*, Prentice-Hall.

MADDALA, G. S. (1984). – *Limited Dependent and Qualitative Variables in Econometrics*, Cambridge University Press.

QUANDT, R. E. (1988). – *The Econometrics of Disequilibrium*, Blackwell.

SHAPIRO, M. D. (1986). – "The Dynamic Demand for Capital and Labor", *Quarterly Journal of Economics*, CI, (3), pp. 513-542.

SIMON, H. (1960). – *The New Science of Management Decision*, Prentice-Hall.

SLADE, M. E. (1984). – *An Econometric Model of the U.S. Copper and Aluminum Industries*, NY: Garland Publishing, Inc.

STUCKEY, J. A. (1983). – *Vertical Integration and Joint Ventures in the Aluminum Industry*, Cambridge, MA: Harvard University Press.

SUSLOW, V. Y. (1986). – "Estimating Monopoly Behavior with Competitive Recycling, an Application to Alcoa", *Rand Journal of Economics*, 17, (3), pp. 389-403.

SWEEZY, P. M. – "Demand Under Conditions of Oligopoly", *Journal of Political Economy*, 47, pp. 568-573.

WOODS, D. W. and BURROWS, J. C. (1980). – *The World Aluminum-Bauxite Market*, Cambridge, MA: Charles River Associates.