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ESTIMATING MONOPOLY BEHAVIOR WITH COMPETITIVE RECYCLING: AN APPLICATION TO ALCOA

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by

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Abstract

This paper develops a structural model of the aluminum industry during the inter-war period taking into account both the intertemporal nature of Alcoa's cost minimization problem and the competitive recycling sector. The model enables estimation of Alcoa's degree of market power, allowing for the effect of competition from recycled aluminum. Previous work has emphasized Alcoa's control over the size of the secondary sector in the long-run as a source of market power for Alcoa. I find that Alcoa could exert little influence in this regard, but nonetheless had substantial market power.

I. Introduction

Prior to World War II, the Aluminum Company of America (Alcoa) was the sole domestic producer of primary, or new, aluminum. Used aluminum was recycled by the competitive secondary sector of the industry. This dominant-firm/ competitive-recycling fringe industry structure spawned a body of research into the effect of a recycling sector on monopoly market power.[1] There are two broad issues raised by a market for recovered aluminum. First, even ignoring

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the fact that the fringe competitors happen to be involved in recovery activity, the supply elasticity of the fringe is an important determinant of the dominant firm's market power. Second, when the recycling aspect of the fringe is recognized, additional problems of an intertemporal nature appear, for example, the extent to which Alcoa actively controlled the long-run size of the fringe. Earlier empirical work on Alcoa has (implicitly) assumed that all aluminum is recycled quickly and that recycled aluminum is identical to new aluminum. This is tantamount to assuming that the intertemporal recycling issue is of principal importance. I shall show empirically that Alcoa's market power over the period 1923-40 should not be attributed to its control over secondary output, but, rather, ought be attributed to Alcoa's steep residual demand curve in a short-run setting.

In developing a structural model of the aluminum industry for the purpose of inferring Alcoa's market power, considerable attention is given in the paper to Alcoa's cost structure. In the short-run, aluminum production marginal cost at the plant level is a right-angle curve with a capacity constraint that occasionally binds. Naive accounting based approaches to determining marginal cost will fail to draw the correct market power inference.[2] Therefore, to try to uncover the true price-marginal cost margin I will treat Alcoa's cost specification with care. Further complications due to inventory holding by Alcoa are also addressed.

The paper is organized as follows. Section II develops the econometric model. It begins by briefly presenting the necessary background on the industry and proceeds from there to specify Alcoa's cost equation and the remaining equations of the model. Section III briefly reviews the data. Section IV presents the results of the estimation. Concluding remarks are given in Section V.

II. Econometric Model of the Inter-War Aluminum Industry

A. Determinants of the Slope of Alcoa's Demand Curve

Prior to 1940 the only potential rivalry Alcoa faced came from a competitive secondary (recovery) sector.[3,4] Secondary aluminum accounted for an average of 20 percent of the market, except during the mid-1930's when its average share rose to 31 percent.

The characteristics of this market suggest a simple dominant-firm/competitive fringe model, where the fringe consists of suppliers of scrap aluminum.[5] (The terms scrap and secondary are used interchangeably.) Market demand and fringe supply are drawn in panel (a) of Figure 1. The residual demand facing Alcoa at any price is the difference between market demand and fringe supply. This residual demand curve for Alcoa is depicted in panel (b). Short-run marginal cost (SRMC) is assumed for now to be smoothly rising.

Figure 1 about here

Many of the key points in the econometric model can be motivated from this diagram. First, the elasticity of the residual demand curve determines Alcoa's market power. This elasticity depends in turn on the elasticity of fringe supply and the elasticity of market demand (Landes and Posner [1981]).

Second, the magnitude of the relevant cross-price elasticities in demand help determine the elasticity of market demand and thus the residual demand elasticity. Figure 1 is drawn for simplicity assuming primary and secondary aluminum are perfect substitutes, with one price ruling the market. A close look at the facts, however, reveals this to be unlikely. Aluminum was still a relatively new metal in the early 1900's and the technology for remelting and purifying aluminum scrap had not been perfected. For this reason recycled aluminum had not gained complete acceptance. Also, the degree of substitutability varied widely with the downstream use. For instance, seconddary was used for castings (in automobiles), but generally not for making sheet and wire products.[6] These facts suggest that primary and secondary are imperfect substitutes. The price of secondary should therefore be included in the estimation of Alcoa's demand equation along with other sources of competition for primary aluminum, such as, steel (in the automobile market) and copper (in the electronics industry).

Finally, there is an intertemporal recycling issue not captured by Figure 1. The empirical question of interest is the extent to which Alcoa actively controlled the long-run size of the fringe. What was the intertemporal effect of the secondhand market on Alcoa's monopoly rents? Most of the theoretical (and therefore empirical) work on the "Alcoa problem" has emphasized the fact that the stock of aluminum available for recycling is endogenously determined by Alcoa. At the time, aluminum scrap was derived primarily from motor vehicles and aircraft. Aluminum was also used in cooking utensils, electric cables, and construction. Lags between original sales and scrapping varied across aluminum products from an average of five years for motor vehicles to at least twenty years for cables and construction uses. These recycling lags, when viewed in conjunction with the imperfect nature of substitutability, lead me to the conclusion that for this sample period long-run competition from the secondary market is not the foremost issue of interest. The model therefore focuses on the constraints on Alcoa's short-run market power. The stock of recoverable aluminum is taken as exogenous, permitting a straightforward estimation of Alcoa's marginal revenue. Indirect tests in the final section of the paper provide evidence to support this assumption that Alcoa's pricing strategy differs trivially whether the stock of aluminum scrap is exogenous or endogenous.

The above arguments yield the first set of general equations of the model:

$$Q_S^D = g_D(P_S,\ P_A,\ X)\quad ,\ Q_S^S = g_S(P_S,\ STK,\ Y),$$

$$\text{and } S_A = f_D(P_A,\ P_S,\ Z),$$

where Q_S^D = quantity of secondary demanded, Q_S^S = quantity of secondary supplied , S_A = Alcoa's sales, P_S = scrap price[7], P_A = Alcoa's price, STK = stock of recoverable aluminum outstanding, and X, Y, Z = exogenous variables.

B. Alcoa's Technology and Supply Decision

The only curve in Figure 1 not yet discussed is Alcoa's short-run marginal cost. The plant level marginal cost curve for primary aluminum production is virtually constant up to plant capacity in the short-run. The essentials of the aluminum production process are commonly described by a fixed coefficient, linear production function: a combination of roughly two pounds of alumina, ten kilowatt hours of electricity, and a few other active ingredients produces one pound of aluminum. The typical aluminum reduction plant is comprised of several "potlines," each containing over 100 individual electrolytic cells or pots. Thus, variable costs are proportional to the number of potlines in operation and, since the process of aluminum production is performed around the clock, small adjustments can be made to output by closing down one or more potlines. (It is more efficient to shut down an entire potline than to operate several potlines far below capacity rates.) However, despite the almost completely divisible, highly flexible nature of current production, it takes roughly three years to bring new capacity on-line.

Therefore, Alcoa's SRMC at a single plant can be represented as in Figure 2, where RATC is Alcoa's real average total cost and RAVC is real average variable cost. When the firm is operating at excess capacity, the relevant marginal cost is defined over variable costs alone. If production is straining capacity in a given year, but positive inventories exist, then all future costs attributable to the current use of capacity should be included. The upper vertical segment of SRMC is relevant if the firm is capacity constrained and inventories have been exhausted.

Figure 2 about here

A firm faced with this short-run marginal cost structure that can hold inventories will be able to smooth production.[8] As Blinder [1982] and Suslow [1983] show, if the firm opts to sell rather than store any of today's production, then the optimizing condition requires marginal cost of producing that unit at time t to equal marginal revenue of selling that unit at t: $MR(S_t) = MC(Q_t)$. This is the final estimating equation of the model.[9]

C. Specifying Alcoa's Marginal Cost and Supply Relationship

The purpose of this section is to make the step from specifying plant level SRMC to firm level SRMC, realizing that Alcoa operated several plants.[10] Cost level differences due to differing technologies across plants were trivial. RAVC is much more likely to be a step function because of variation in electricity costs and/or differing vintages of plants. Even if there were no a priori reason to expect differences in RAVC across plants, constant marginal cost assumptions must be approached with caution, given the purpose of this study. If Alcoa's supply relationship is in fact positively sloped while RAVC is assumed to be constant, this will be interpreted by the model as market power.[11] The slopes of the demand and cost curves must be carefully disentangled in order to identify Alcoa's residual demand elasticity.

I deal with these issues in the following way: the most tractable form for SRMC is linear. If the first units were produced much more efficiently, then SRMC could be convex to the origin. If costs were more evenly distributed across plants, SRMC could be linear or mildly concave. I allow for different curvatures in order to test whether the results presented below are an artifact of the linear SRMC specification.

In the estimating model SRMC is allowed to be a function of excess capacity. The upper bound is taken as RATC. Thus, let the linear version of SRMC be

$$\text{(4)} \quad SRMC^{*} = \gamma(K_A - Q_A)RAVC + [1 - \gamma(K_A - Q_A)]RATC,$$

where γ is an unknown parameter, K_A is Alcoa's primary aluminum capacity, and and Q_A is Alcoa's primary aluminum production.[12] If γ takes on the value zero or $1/(K-Q)$, SRMC will be estimated as constant at the level of RATC or RAVC, respectively. Intermedite values of γ will produce a line with slope $\gamma(RATC - RAVC)$.

The discussion thus far has covered two cases for Alcoa's equilibrium. Either $MR_A = SRMC^{*}$, specified in equation (4), or $MR_A = RATC$, when the firm's capacity constraint binds. If a stockout occurs (Alcoa produces to capacity and draws inventories down to "zero"), then a third regime is appropriate where price is demand determined. Let $MR_{At} = P_{At} + \theta S_{At}$, where $\theta = dP_A/df_D$. The final form of Alcoa's supply relationship is (suppressing the subscript A):[13]

$$\text{(5)} \quad P_t = \begin{cases} -\theta S_t + SRMC^{*}_t, & Q_t < K_t \\ -\theta S_t + RATC_t, & Q_t = K_t \text{ and } S_t < K_t + I_t \\ f_D^{-1}(K_t + I_t), & S_t = K_t + I_t \end{cases}$$

In the naive case SRMC is forced to be constant (i.e., equal to RAVC) until capacity is reached. If this restriction is incorrect, the system represented by (5) run under a relaxation of the right-angle SRMC should yield different coefficients and a higher likelihood. Both nested and non-nested hypothesis tests can be performed.

D. Completing the Model

Given that our focus is Alcoa between the wars, only 18 annual observations are available. A parsimonious model is constructed in order to conserve degrees of freedom. Primary and scrap aluminum demands are specified in log-log form. This choice was made for ease of interpretation of the elasticities. The demand equations are:

$$(6)\quad \log S_{At} = \alpha_0 + \alpha_1 \log P_{At} + \alpha_2 \log P_{St} + \alpha_3 \log PSTL_t$$
$$+ \alpha_4 \log FED_t + \alpha_5(\Delta FED_t)$$
$$+ \alpha_6 \log QAUTO_t + \alpha_7\ TIME_t + u_{1t}$$

and

$$(7)\quad \log Q_{St} = \delta_0 + \delta_1 \log P_{St} + \delta_2 \log P_{At} + \alpha_3 \log PSTL_t$$
$$+ \alpha_4 \log FED_t + \alpha_5(\Delta FED_t)$$
$$+ \alpha_6 \log QAUTO_t + \alpha_7\ TIME_t + u_{2t},$$

where,

S_A = Alcoa's sales of primary aluminum

Q_S = production of scrap aluminum[14]

P_A = real price of 99+% pure aluminim ingot

P_S = real price of cast aluminum scrap

STL = real price of steel

FED = Federal Reserve Index of Durable Manufacturing (1947-49=100)

ΔFED = $(FED_t - FED_{t-1})/FED_{t-1}$

QAUTO = U.S. passenger car factory sales

TIME = time trend.

Detailed variable definitions are in Appendix A, Table A.1. All nominal prices are deflated by the implicit GNP deflator (1958=100). The price of copper was excluded from the final specification, based on its insignificance in early runs of the model. Note that the exogenous demand variables have been constrained to have the same effect on primary and scrap demand.[15]

A few of the exogenous variables have not been discussed previously, namely FED, ΔFED, and QAUTO. Given that aluminum is used primarily in durable goods, the derived demand should be cyclical in nature. One might expect to find ΔFED, the relative change in "income", as well as FED to be an important determinant of demand. Sectoral shifts in addition to economy-wide changes could also help determine the placement of Alcoa's demand curve. QAUTO is therefore included to reflect the fact that the auto industry was aluminum's major market throughout the sample. A time trend is added to capture autonomous changes in demand.[16]

Scrap supply is specified as follows:[17]

$$(8)\quad \log\left(\frac{Q_{St}}{STK_t + Q_{St}}\right) = \beta_0 + \beta_1 \log P_{St} + \beta_2\, TIME_t + u_{3t}.$$

STK_t is defined as an end-of-period variable: it represents last period's stock of scrap as yet not recovered, plus new additions to the stock, minus the quantity of secondary recovered in the current period. As secondary supply decisions for the current period are made based on the beginning-of-period available stock of aluminum, the denominator of (8) is defined over $STK_t + Q_{St}$. Note that STK is excluded from the demand equations. It therefore performs an important function in being one of the exogenous variables which will identify demand.

The functional form assumptions given in (6) - (8) dictate the exact specification of Alcoa's residual demand and therefore of the derivative term in Alcoa's supply relationship (5). If the price of scrap were independent of

Alcoa's actions, the derivative of log P_A with respect to log S_A would be simply $1/\alpha_1$. If the recycling sector has some contemporaneous effect, the total derivative will be a more complicated expression. Solving (8) for Q_S, equating it to (7), taking the total derivative, and then substituting into the total derivative of (6) yields

$$\theta \equiv \frac{dP_A}{dS_A} = (1/\eta)\,\frac{P_A}{S_A},$$

where $\eta = \alpha_1 + \dfrac{\alpha_2\delta_2}{\beta_1 - \delta_1}$ [18].

As the discussion of Figure 1 suggested, marginal revenue for Alcoa in (5) is a function of the own- and cross-elasticities of demand as well as the elasticity of scrap supply.

Equation (5) implies a switching regressions framework for the model. As a rule, one would want to estimate the model with the regimes endogenously determined. In this particular sample Alcoa clearly appears to be either capacity constrained and drawing down inventories (1923-27, 1937-40) or far short of capacity (1929-36). The only year in which sales remotely approached capacity plus inventories was 1928. The regimes are treated as known in each year without the loss of essential information.

III. Data

The data used for this model are presented and discussed in detail in Suslow [1983]. Appendix A of this paper presents the relevant data definitions and sources. In this section the major innovations in the data are very briefly enumerated.

(1) Previous studies have used Alcoa's list price. Transactions price data are available for 1931-37. The price series used here is formed by splicing together the list price and transactions price series presented

in Table A.2. Since the aluminum industry experienced boom years from 1924-29 and 1939-40, it is reasonable to presume that the list price during these years is a good estimate of the transactions price. However, between 1931 and 1934 the sales price declined much more sharply than the list price. This data should yield more accurate estimates of Alcoa's demand elasticity.

(2) Data on sales of aluminum in all forms by Alcoa are available for 1926-35. Fisher [1961] worked with this early data. Starting in 1929 there are much more reliable data on changes in Alcoa's stocks of primary ingot. These data are used to form Alcoa's sales variable.

(3) In the literature to date, STK has been defined as cumulative consumption over time, with last year's total consumption appearing as an addition to this year's stock. In this paper STK represents a distributed lag on aluminum used in the significant aluminum-bearing goods that might be recycled within the sample period, i.e., all transportation vehicles. The estimate of the timing of aluminum derived from scrapped aircraft is probably fairly inaccurate. This should not greatly alter STK since aluminum from "junked" motor vehicles dominates the STK series. The timing of motor vehicle scrappage is based on data on average motor vehicle lifespan over the sample. Auto scrappage data is used to correct for the fact that during the mid-1930's consumers did not scrap their cars as frequently as in prior years. STK is calculated independent of price and is certainly biased downward. However, the upward bias inherent in cumulative consumption is far more grievous. The trend in the STK series is a cyclical one, growing to a peak in 1933 (a reflection of large amounts of aluminum used in cars in the 1920's) and then gradually falling due to both a decline in the scrappage rate of cars in the early 1930's and wartime pressures on aluminum demand.

(4) The cost data come from the trial record and are known as "average mill costs". These are the mill cost of producing pig aluminum net of profits of direct subsidiaries. Included in mill costs are all variable costs and some fixed costs attributable to plant overhead, such as depreciation, property taxes, and insurance.[19] The mill cost figures do not include interest, federal income taxes, and home office overhead. Real average mill costs are used as a proxy for long-run average total costs. At capacity, average fixed costs are roughly 23 percent of average mill cost.[20] Assuming total fixed costs are constant in real terms, RAVC is calculated by subtracting out the fixed component.[21]

IV. Empirical Results

The system to be estimated consists of the four equations described by (5)-(8), where (5) is imposed as a contraint on the system. The endogenous variables of the system are S_A, P_A, Q_S, and P_S. There is no structural equation determining Alcoa's production: $\hat{Q}_A$ is therefore predicted from a reduced form regression, and the estimates are obtained by a limited information maximum likelihood procedure.[22] Note that even in the naive model equation (5) contributes to the likelihood function through the elasticity parameters from (6)-(8) that reappear in (5).

A. Basic Results

The estimates obtained with right-angle SRMC are presented in Table 1.[23,24] Except for the price of steel, all coefficients have the correct sign. The most important coefficients, the demand and supply elasticities, are more precisely estimated. Additional power is gained from having these parameters appear twice in the system.

Table 1 about here

Table 2 presents the results using equation (4) to specify SRMC. $SRMC^*$ is obviously superior in fit: log L jumps from its previous value of 24 in the naive model to roughly 38. The magnitude of the increase in the likelihood makes it apparent that Alcoa's SRMC during excess capacity years was rising, although not rapidly. At the mean, $\hat{\gamma} = 0.08$ implies a derivative of SRMC with respect to Q of 0.005. (At the mean $SRMC^* = .17$ and Q = 97,300 tons.)

It is interesting to note that these estimates offer one explanation for the surge in the secondary sector's market share during the Depression. The estimates show a scrap supply curve that is elastic (1.62), but not highly so, and a SRMC curve for Alcoa that is fairly flat. In such a case one would expect demand shocks to be absorbed primarily by Alcoa.

Table 2 about here

A repeated claim in earlier empirical work has been that short-run demand for aluminum is inelastic. This statement properly refers to the demand for aluminum of all kinds, not to the demand for primary ingot alone. Only aggregate demand functions have been estimated previously. Not surprisingly, much smaller elasticities of demand were found. Fisher [1961] estimated the demand for all domestic aluminum and found a price elasticity of -0.43. Mason's [1972] estimate for a similarly specified regression is -0.95. Mason does not adjust for stockpiling by Alcoa.

Table 2 shows that the own-price elasticity of Alcoa's structural demand curve is fairly high, at a value of -2.08. A one percent increase in Alcoa's price will thus lead to a decrease in sales of roughly 2,000 tons at the mean. The elasticity of Alcoa's sales with respect to a change in the price of <u>scrap</u> is slightly more than half this magnitude.

Two further remarks are in order. First, in results not reported here imports are found to have a negligible effect.[25] Second, it may appear surprising that an increase in durable manufacturing activity of one percent yields only a 0.11 percent increase in aluminum demand. Unfortunately, a clear interpretation of the coefficient on FED, α_4, cannot be made due to multicollinearity of FED and QAUTO.[26]

Because one is apt to confuse market power inferences with the slope of the marginal cost curve I have considered alternative cost functions of the form SRMC = RAVC + γh(K-Q)*[RATC-RAVC]. The simplest is a γ-weighted average of RAVC and RATC (i.e., $h_0(K-Q) = 1$). The other two functional forms are $h_1(K-Q) = \frac{1}{K-Q}$ and $h_2(K-Q) = (K - (\frac{K-Q}{c})^2)$, where c is a constant that was varied across different runs of the model. The h_1 and h_2 specifications lead to convex and concave SRMC, respectively. The results of the maximization are $\log L(h_0) = 27.71$ ($\hat{\gamma} = .5$, significantly different from zero and one), $\log L(h_1) = 25.88$, and $\log L(h_2) = 38.35$. All rapidly rising formulations of SRMC were rejected on the basis of significantly lower log likelihood. All slowly rising specifications performed almost identically to the linear version SRMC*.[27] The point estimates of the own-scrap demand elasticity and the cross-demand elasticities move around across specifications, but are not significantly different. The two most robust parameters are the scrap supply elasticity and Alcoa's residual demand elasticity.

B. Measuring the Extent of Alcoa's Market Power

Landes and Posner [1981] point out that market share alone is not a sufficient statistic for measuring market power if the fringe supply elasticity is unknown. Alcoa's structural demand elasticity, assuming P_S fixed, is estimated at -2.08. Using Table 2, the <u>total</u> effect of an increase in P_A on S_A, taking into account the response of the secondary sector, is

$$\hat{\eta} = \frac{d\log S_A}{d\log P_A} = \underset{(0.03)}{-1.67} ,$$

or a Lerner index of fifty-nine percent.

To see the effects of a change in fringe supply elasticity on Alcoa's estimated residual demand elasticity, consider the following experiments. First, let fringe supply be vertical through the actual supply point. The elasticity of Alcoa's residual demand curve, holding Q_S fixed, is $\hat{\eta}_{Q_S} = -0.76$.[28] In this case an increase in Alcoa's price would have little effect on its sales. Second, let fringe supply be horizontal. Holding P_S fixed yields $\hat{\eta}_{P_S} = -2.08$, from Table 2. Alcoa loses substantial sales to the secondary market as it tries to increase its price. While the <u>actual</u> case ($\hat{\eta} = -1.67$) is significantly different from the case of Q_S fixed, it does not differ significantly from $\hat{\eta}_{P_S}$. That is, scrap supply was far from completely vertical. Alcoa's market power <u>could</u> have been measurably lessened by competition from the fringe. Only because new and used aluminum were not perfect substitutes was Alcoa able to retain its market power.

To summarize, prior to 1940, even accounting for the contemporaneous impact of the recycling sector, Alcoa had sufficient market power to have a Lerner index of approximately sixty percent. The source of Alcoa's market power was not so much inelastic fringe supply as it was less than perfect substitutability with the fringe's product.

C. Some Comments on Intertemporal Competition

A rough estimate of the intertemporal effect of recycling can be found with a few additional calculations. The question of interest is how the residual demand elasticity estimated above differs from the residual elasticity in the steady state, which has been of great theoretical concern. We have,

$$(9)\quad \left.\frac{d\log P_A}{d\log S_A}\right|_{\substack{\text{Steady}\\ \text{State}}} = \frac{d\log P_{At}}{d\log S_{At}} + \text{PDV}\,\frac{d\log STK_{t+k}}{d\log S_{At}}\;\frac{d\log P_{At+k}}{d\log STK_{t+k}}\left.\vphantom{\frac{d}{d}}\right|_{Q_S^D = Q_S^S} .$$

All of the above terms have been estimated, except for the effect of a change in Alcoa's current sales on future STK.[29] Conservatively, assume that thirty-five percent of S_{At} comes back as STK in year t+8 and an interest rate of five percent.[30] Then the average steady state Lerner index is estimated as 0.65 (standard error 0.09), an eight percent increase over Alcoa's short-run markup. Alternatively, one could ask by how much $\hat{\alpha}_1$ is biased, given that the intertemporal effect is not modeled. At the mean, the markup of Alcoa's price over RATC implied by the data is roughly sixty percent. Taking this figure as the true steady state markup, the corrected demand elasticity becomes -2.21 (s.e. 1.05),[31] an increase of six percent. Neither of these differences is large.[32]

V. Concluding Remarks

This paper has specified structural supply and demand equations for secondary aluminum and an empirical model for a dominant firm facing a competitive fringe. The model has taken care to be very explicit about the dominant firm's cost curve so as not to confuse costs with market power. Alcoa had substantial market power, although not for the reason commonly attributed to it by previous work or by Judge Learned Hand in the famous Alcoa case. Given that the current stock of recoverable aluminum was an imperfect substitute for Alcoa's product and that there were lengthy recycling lags, the "Alcoa problem" was not very important to Alcoa.

NOTES

1. Friedman's [1966, pp. 278-279] original query about the famous Alcoa monopoly case (United States v. Aluminum Company of America, 148 F. 2d. 416 [1945]) sparked much of the literature. Previous empirical studies have been performed by Fisher [1961] and Mason [1972]. Gaskins [1974] and Swan [1980] focus on Alcoa's theoretical steady-state markup under varying assumptions about the conditions for scrap resale and the degree of vertical integration. In addition, their articles end with a short empirical section. All these studies estimate reduced form equations and/or use simulations.

2. Bresnahan [1982].

3. There were about eight recycling firms in the late 1920's, twelve in 1930, and twenty-five in 1941. See Mason [1972, p. 30] and Anderson [1931, p. 12].

4. Imports were rarely significant due to domestic tariff protection (tariff rates represented about twenty percent of the primary aluminum price) and a European cartel. The cartel formally functioned during the years 1901-08, 1912-14, 1926-30, and 1931-40. The cartel of 1926-30 was relatively ineffectual. It was reorganized in 1931 to become a much stronger force. Over the sample period Alcoa was not directly involved in the cartel, but there seemed to be implicit reciprocal agreements between Alcoa and the cartel against exporting into each other's territory. For more detail see Carr [1952, p. 80], Lanzillotti [1961, pp. 190-193], and Wallace [1937, pp. 93-94, 304].

5. Scrap here refers only to old scrap, i.e., that scrap retrieved from aluminum-bearing products. Shavings and clippings created by the stamping process are known as new scrap, and are counted as part of primary production. For example, if Alcoa created new scrap in the production process and fed it back into the system it would eventually be counted as part of Alcoa's primary production. The same result holds if the new scrap was sold by a fabricator to a secondary producer who remelted it and resold it at the secondary price. That transaction does not negate the fact that this new scrap was originally sold to the fabricator by Alcoa in primary form. New scrap is therefore treated as part of current primary output, valued at the primary price.

6. U.S. v. Alcoa, 44 F. Supp. 97 (1941), p. 424.

7. A complete data series on scrap prices is attainable for the period, while only a partial series can be found for the secondary price. Since very little alloying was done at the time, the quantity of secondary aluminum produced and the quantity of scrapped aluminum recovered should differ by a constant of proportionality. Therefore, the model uses the scrap sector to capture the response of recyclers to a change in Alcoa's price.

8. One observes that Alcoa did, in fact, follow a practice of producing up to capacity and storing the excess supply in ingot form, <u>except</u> during protracted demand downturns. Only at the height of the Great Depression did Alcoa close its oldest plant. Before doing so it accumulated roughly five months of production in 1930 alone. Similarly, in the short-lived downturn of 1938, more than one-third of the annual output that year was stored as inventory.

9. Should Alcoa choose to produce for sale next period, marginal production cost plus marginal inventory holding cost must equal the discounted marginal revenue from selling that unit in the future. Since this model emphasizes short-run behavior, the latter optimal inventory relationship is not estimated.

10. Alcoa's plants and their initial year of aluminum production were: Niagara Falls (1985), Shawinigan Falls (1901, Canada), Massena (1903), Alcoa (1914), Badin (1917), and Arvida (1926, Canada).

11. Bresnahan [1981], especially pp. 14-16.

12. Different parameters, γ_1 and γ_2, are not used due to the small sample size.

13. The discontinuities in this equation are smoothed out in practice by replacing (5) with

$$\frac{\exp(N \cdot SRMC^{*}) + \exp(-N \cdot RATC)}{\exp(N) + \exp(-N)},$$

where N is a number large enough to make the above ratio approximate $SRMC^{*}$ or RATC at every sample point.

14. The secondary demand equation is specified in terms of production because there are no data on sales of remelted aluminum. Technology of secondary supply is such that large output inventories should be uncommon. Over the period 1967-80, for instance, the secondary sector held an average of four percent of total industry inventories (<u>Aluminum Statistical Review</u>, 1980, p. 27). Note that the model also assumes that consumers hold no inventories. Given the small amount of aluminum used per final good, it

probably was not worth holding large inventories at the intermediate stage of production during the sample period. There is no data to check the assumption.

15. Although implausible in certain respects, this was done to conserve parameters. Potentially, the most important loss of information relates to the constraint on QAUTO. A large part of secondary production went to the auto industry; thus, the effect on QAUTO on scrap demand could be considerably larger than its effect on Alcoa's sales. However, experiments allowing the QAUTO coefficients to vary showed no significantly different cross-equation effects.

16. Comments were made on early drafts of this paper which questioned the validity of the structural interpretation of the results, given that the sample spans the Great Depression. The time trend was included to answer some of these doubts.

17. The industry supply curve should depend on number of firms, but data are essentially not available. If the composition of STK is roughly constant, which is not an unreasonable assumption, then STK can proxy for the number of firms. Also, there are no data available on factor prices in the scrap sector. However, changes in STK, as opposed to changes in factor prices, are much more likely to be the driving force in shifting the supply curve of scrap. A wage series from the steel industry was tried in early specifications and consistently produced the wrong sign. The harm from using this poor proxy for the actual wage series was deemed more severe than the bias from omitting wages entirely.

18. Given that equation (8) is specified in terms of beginning-of-period stock, β_1 should be multiplied by $(1 - Q_S/STK)$. The mean of Q_S/STK over the sample is 0.26 and ignoring this should not alter the results significantly.

19. Average mill cost data are available from the trial record only for the years 1926-37. The general categories included in the mill cost of pig aluminum are: pot lining, carbon rodding, power, potrooms (includes alumina and labor), miscellaneous plant expense, transportation on consigned aluminum, depreciation, plant administration, and repairs and maintenance (see Engle, et al. [1945, p. 214]). Mason [1972] predicts mill costs for the remaining years from data on electricity costs, the most important variable input into the production process other than alumina itself. The estimates obtained are imprecise, but not out of line with the actual series for the overlapping years.

20. Simone [1962, p. 207]. This estimate was made for 1949, a near capacity-constrained year.

21. RAVC = RATC - [(0.23*(K/Q))*0.14], where 0.14 is RATC for the year 1949 (see above footnote). The term in brackets is real average fixed costs, where an adjustment has been made for output rate. (When capacity is underutilized, total fixed cost should be a larger percentage of total cost.) Previous empirical treatment of Alcoa's costs has been haphazard. Mason [1972, pp. 150 and following] calculates average variable cost throughout the sample as 77 percent of <u>nominal</u> average mill costs.

22. Note that Q_A appears twice in the system: once in the inequality constraints of (5) and once in the extensions of Alcoa's cost function, $SRMC^*$. The first instance occurs outside the estimation process. Still, using predicted $\hat{Q}_A$ from the reduced form rather than Q_A leads to the identical categorization of the sample into the three regimes.

23. The estimates reported here were obtained by using the TSP statistical package and are accurate to three decimal places using several divergent starting values. The TSP model used for calculating log L can result in positive or negative values.

24. Tests for serial correlation were made and proved inconclusive.

25. A dummy variable, MDUM, was added to Alcoa's demand equation. MDUM takes on a value of one from 1923-30 and is zero otherwise. One would expect that during those years when the cartel was least effective (1923-30) Alcoa's sales would decline, resulting in a negative coefficient for MDUM. The estimated coefficient is -0.25, however, it is insignificantly different from zero.

26. Classically, there is no cure for multicollinearity. But with such a small sample there may be advantages to dropping a colliner variable. Appendix B of Suslow [1983] contains the results excluding QAUTO. Performance of the model without QAUTO was comparable to that reported in the text. Two differences are most noticeable. One is that Alcoa's structural demand elasticity declines in absolute value to -1.48. However, the point estimate is not significantly different from that reported in Table 2. Second, the cross-elasticity of scrap demand with

respect to Alcoa's price is consistently negative. It is insignificantly different from zero, though, so that the negative sign is unimportant though conceptually disturbing.

27. At this point it is worth repeating that in the right-angle specification capital costs enter SRMC only in peak-load periods (through RATC). These attempts at using other functional forms for SRMC allow capital costs to matter more in the capacity unconstrained states.

28. In order to calculate Alcoa's structural elasticity under the assumption of constant Q_S, the demand system has to be inverted. The total derivative of the inverted demand system is

$$\begin{vmatrix} \text{dlog } P_A \\ \text{dlog } P_S \end{vmatrix} = \frac{1}{\phi} \begin{vmatrix} \delta_1 & -\delta_2 \\ -\alpha_2 & \alpha_1 \end{vmatrix} \begin{vmatrix} \text{dlog } S_A \\ \text{dlog } Q_A \end{vmatrix},$$

where $\phi = (\alpha_1\delta_1 - \alpha_2\delta_2)$. From this one finds $\hat{\eta} = -0.76$ (standard error 3.46). (The residual elasticity is again roughly -1.67.)

29. Solving for equilibrium in the market for secondary and substituting into Alcoa's inverted demand equation yields

$$\text{dlog } P_A = \left(\frac{\delta_1}{\phi} - \frac{\delta_2\alpha_2}{\phi^2\omega}\right) \text{dlog } S_A + \frac{\delta_2}{\phi\beta_1\omega} \text{dlog STK},$$

where $\omega = \frac{\alpha_1}{\phi} - \frac{1}{\beta_1}$, and $\phi = \alpha_1\delta_1 - \alpha_2\delta_2$. Plugging in the estimated coefficient from Table 2 generates

$$\frac{\text{dlog } P_{At+k}}{\text{dlog STK}_{t+k}} = \underset{(0.37)}{-0.19}\ .$$

30. The fraction of aluminum sales in year t which becomes part of the stock of scrappable aluminum in year t + 8 varies from approximately one-fifth to one-half over the sample. I have merely taken the midpoint for expositional purposes.

31. The corrected demand elasticity, α_1^*, is defined implicitly by

$$\left| \frac{\mathrm{dlog}\ P_A}{\mathrm{dlog}\ S_A} \right|_{\substack{\text{Steady}\\ \text{State}}} = \hat{\eta} + \mathrm{PDV}\,\frac{\mathrm{dlog}\ P_{At+k}}{\mathrm{dlog} S_{At}} = -0.60$$

or,

$$\left(\alpha_1^* + \frac{\hat{\alpha}_2\hat{\delta}_2}{\hat{\beta}_1 - \hat{\delta}_1}\right)^{-1} -0.05 = -0.60.$$

$$\Rightarrow \alpha_1^* = \underset{(1.05)}{-2.21} .$$

32. In a comment on Gaskin's 1974 article, Fisher [1974] makes this same point. He argues that while the exclusion of secondary aluminum from the market was a theoretical error, "[g]iven the facts of the Alcoa case, that exclusion did not affect the outcome" (p. 359).

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Table 1

Basic Results
(Log-log form)
(Standard errors in parentheses)

Equation	Const.	P_A	P_S	PSTL	FED	ΔFED	QAUTO	TIME	γ	SSR
Primary Demand (S_A)	-5.49 (5.83)	-1.93 (0.50) t = 3.86	0.89 (0.57) 1.56	-0.05 (0.65)	0.22 (0.35)	0.37 (0.16)	0.43 (0.38)	2.85 (2.37)	-- --	2.68 --
Scrap Demand (Q_S)	-7.11 (4.71)	1.08 (1.39) .78	-0.88 (0.98) .90	-0.05 (0.65)	0.22 (0.35)	0.37 (0.16)	0.43 (0.38)	2.85 (2.37)	-- --	3.00 --
Scrap Supply (Q_S)	1.18 (0.75)	-- --	1.96 (0.67) 2.93		-- --	-- --		1.80 (3.51)	-- --	4.02 --
Primary Supply (P_A)	(Right-angle SRMC)								--	0.01

N = 17
logL = 24.557

Table 2

Results for Linear SRMC
(Log-log form)
(Standard errors in parentheses)

Equation	Const.	P_A	P_S	PSTL	FED	ΔFED	QUATO	TIME	γ	SSR
Primary Demand (S_A)	-1.62 (6.85)	-2.08 (0.76) 2.74	1.25 (0.52) 2.40	0.59 (0.63)	0.11 (0.43)	0.26 (0.13)	0.38 (0.42)	2.38 (2.74)	-- --	4.06 --
Scrap Demand (Q_S)	-3.73 (5.53)	0.77 (1.43) 1.54	-0.73 (0.59) 1.24	0.59 (0.63)	0.11 (0.43)	0.26 (0.13)	0.38 (0.42)	2.38 (2.74)	-- --	2.91 --
Scrap Supply (Q_S)	0.74 (0.86)	-- --	1.62 (0.73) 2.22	-- --	-- --	-- --		1.21 (2.72)	-- --	2.46 --
Primary Supply (P_A)	(Linear SRMC up to capacity)								0.08 (0.03)	0.004 --

N = 17
logL = 37.875

Table A.1

Data Sources*†

Variable Name	Definition	Source(s)
AMC	Alcoa's average mill cost	1923-25, estimated by Mason, Table (5-4), p. 146 1926-27, U.S. v. Alcoa, Exhibit 717, March 8, 1939 reprinted in Mason Table (5-2), p. 149 1938-40, estimated by Mason, Table (5-4), p. 156
FED	Federal Reserve Index of Durable Manufacturing (1947-49 = 100)	1923-40, Mason, Table (4-3), p. 116
GNP	Implicit GNP deflator (1958 = 100)	1923-40, Historical Statistics
S_A	Alcoa's sales of primary aluminum	1923-24, no data available 1925, Benham 1926-28, Wallace, Table 27, p. 325 ("sales of aluminum in all forms by Alcoa") 1929-40, MY 1939, p. 642, fn. 3, and MY Review of 1940, p. 641, fn. 2 ("changes in producer's stocks")
K 1/	Alcoa's estimated primary production capacity	1923-28, Wallace, p. 247 (point etimate) 1929-37 1/, Wallace, p. 78 (point estimate) 1938-39, NDH, Part 3, p. 783 1940, ABMS, 1941, p. 99
M	Total imports of crude, scrap, alloy, and fabricated aluminum	1923-40, MS, various issues
P_A 2/	Alcoa's price of 99+% pure aluminum ingot	1923-32, Wallace, Table 13, p. 240 (list price) 1931-37, U.S. v. Alcoa, 44F. Sup. 97(1941), p. 284 (sales price) 1933-40, MtI and MI, various issues (list price)
PSTL	Price of Bessemer steel billets (Pittsburgh) ($/long ton)	1923-40, MS, 1953, p. 262
P_S	Price of cast aluminum scrap	1923-26, Anderson, Figure 18, p. 100 and MI 1927-40, MS ("dealer's buying prices at New York f cast aluminum scrap")

Table A.1

Data Sources (Continued)

Variable Name	Definition	Source(s)
Q_A	Alcoa's production of primary aluminum	1923-40, MS
QAUTO	U.S. passenger car factory sales	1923-40, MS
Q_S[3/]	Recovery of secondary aluminum from old scrap	1923-28, estimated[3/] 1939-40, MS
STK[4/]	Stock of recoverable aluminum	estimated[4/]

Table A.1: Data Sources (Continued)

NOTES:

* all prices are ¢/lb. and all quantities are short tons of 2,000 pounds unless otherwise noted.

† See Table A.2 for key to references cited.

1. For the years 1931-35 $K = K_{1929-37} - 20{,}000$, due to the shut down of Alcoa's Niagara Falls plant (see MI 1931, p. 15). Capacity of the Niagara plant is estimated at 20,000 tons (see MaS, p. VII-9). ABMS lists Niagara's capacity in 1943 as 22,000 tons, but this is wartime capacity. In January 1936 the Niagara plant was reopened (MI, 1936, p. 14).

2. Alcoa's list price changed infrequently. Wallace (Table 13, p. 240) provides data on the list price and approximate dates of price changes for the years 1922-32. Two trade journals of the period, Metal Industry and Mineral Industry (MtI, and MI), also give reasonably frequent information on Alcoa's list price. These three sources were checked against each other for consistency. When a discrepancy was found the data from MtI and MI were used rather than Wallace. PLIST was calculated as an average, using the fraction of days during the year when the given list price reigned. (In MtI and MI, dates were often not given for the price changes, so they are centered at the 15th day of the month in question.) The raw data are given in Table A.2 of this appendix (some of these figures are reprinted from Wallace).

3. $Q_S = SEC - 0.13Q$, where SEC = total secondary recovery. This calculation is based on Anderson's [1931] estimate that new scrap clippings resulting from aluminum sheet production amounted to 13 percent of total production in 1929. In 1939, when data became available, the corresponding figure is ten percent.

4. STK is an estimate of the amount of aluminum in the junkyards available for purchase by the scrapping sector of the aluminum industry. See pp. 70-74 and pp. 112-113 of Suslow [1983] for a full discussion of the assumptions made and data used in calculating STK.

Table A.2

Key for Data References

Abbreviation	Source*
ABMS	American Bureau of Metal Statistics Yearbook
Anderson	Anderson [1930]
Engle	Engle [1945]
Mason	Mason [1972]
MI	Mineral Industry
MS	Metal Statistics
MtI	Metal Industry
MY	Minerals Yearbook
NDH	National Defense Hearings [1941]
Wallace	Wallace [1937]

*Full citation given in references

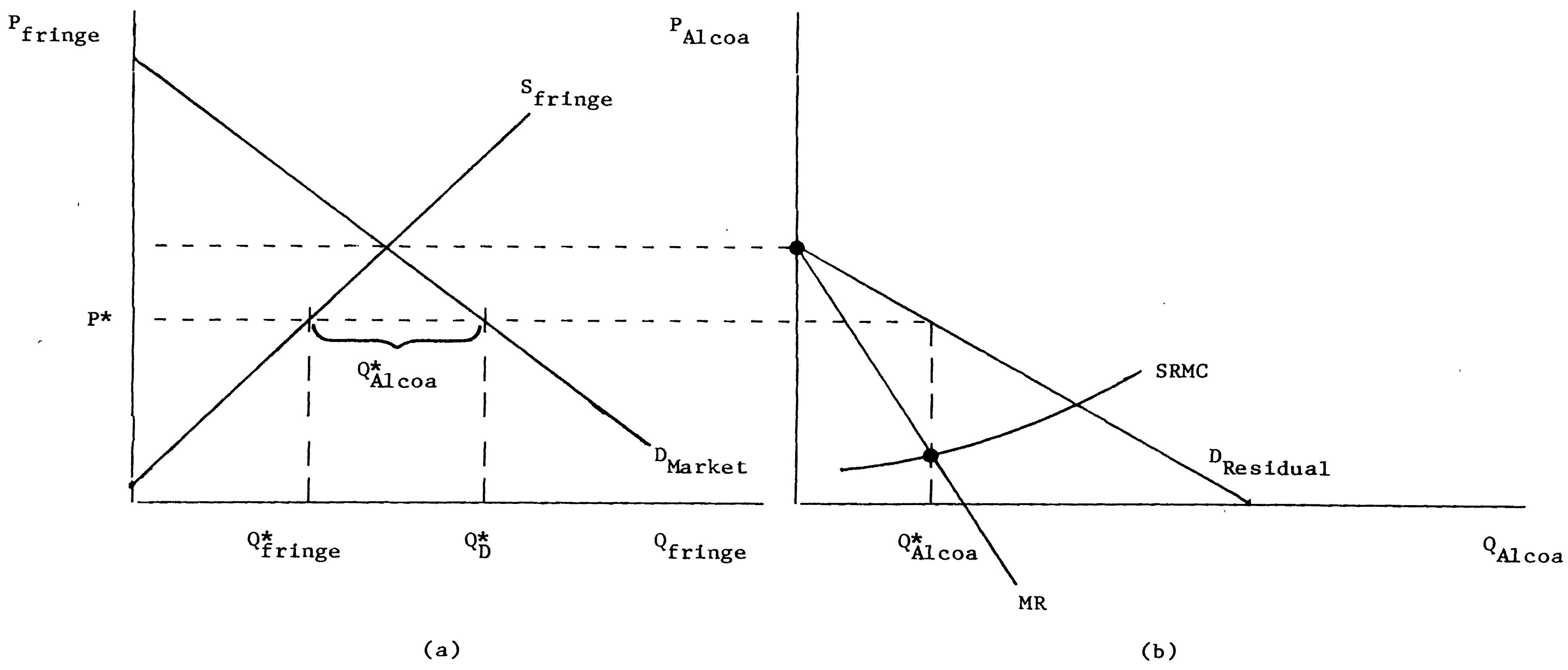
Raw Data for Alcoa's List Price

Year	Data of Price Change (Approx.)	New List Price[a] (¢/lb.)	Transactions Price (¢lb.)[b]
1922	January 1	20.0	--
	September 26	22.0	--
	November 1	23.0	--
	November 22	25.0	--
1923	February 7	26.0	--
	November 23	27.0	--
1924	February 15	29.0	--
	May 15	28.0	--
1925	October 22	29.0	--
	December 17	28.0	--
1926	July 1	27.0	--
1927	January 15	26.0	--
	October 20	25.0	--
	December 21	24.3	--
1928	No change	--	--
1929	No change	--	--
1930	June 26	23.3	--
1931	No change	--	22.78
1932	No change	--	21.76
1933	No change	--	19.30
1934	October 15	22.0	18.95
1935	No change	--	18.75
1936	No change	--	18.82
1937	March 1	20.0	19.56
1938	No change	--	--
1939	No change	--	--
1940	March 24	19.0	--
	August 1	18.0	--
	November 15	17.5	--

[a]See Footnote 2 of Table A-1 for a discussion of the sources for this table.

[b]Source: U.S. v. Alcoa, 44F.Supp. 97(1941), p. 284.

<u>Figure 1</u>



P fringe
S fringe
P*
Q* Alcoa
D Market
Q* fringe
Q* D
Q fringe
P Alcoa
SRMC
D Residual
Q* Alcoa
Q Alcoa
MR
(a)
(b)

Figure 2