EG & EA

WORKING PAPERS

THE MEASUREMENT OF FIRM COST CURVES

Robert P. Rogers

WORKING PAPER NO. 96

November 1983

BUREAU OF ECONOMICS
FEDERAL TRADE COMMISSION
WASHINGTON, DC 20580

I. Introduction

For many oligopolistic industries, cost conditions may preclude the competitive equilibrium where price equals marginal cost. In such industries, firm average costs are falling in the relevant ranges of output, so a price equal to marginal cost would result in receipts less than total outlays. Consequently, in the long-run, firms would leave the market. Some economists have suggested that efficiency requires subsidies to help implement marginal cost pricing, but such policy may not necessarily be optimal in a macro-sense (see Baumol 1979). Others have posited that some form of collusion is needed for these industries to survive unaided by the rest of society (see Bittlingmayer 1982).

Many writers have asserted that in the short-run the American steel industry may fit these conditions, and some empirical evidence points to such a conclusion. Rowley (1971) gives a summary of this evidence but does not himself subscribe to this view of steel firm cost curves. Instead he asserts that the actual short-run curves loosely resemble the U-shaped curves presented in most economics text books and that steel firms usually operate on the upsloping portions of these curves.

Rowley bases his conclusion on a study of the American steel industry using activity analysis which shows that the steel firms use several different technologies of varying efficiencies (see Tsao 1970). In addition, most large steel companies are multi-plant, and their plants usually have somewhat different cost situations. The seemingly logical reaction of the firms, then, would be to use the most efficient plants and processes at low levels of output and bring into production the higher cost plants as demand and capacity utilization increases. Consequently, at most output levels the firms would face rising short-run cost curves, and profitable marginal cost pricing would be possible. While with U-shaped cost curves, the small numbers collusion problem may still exist, the possible necessity for collusion discussed by Bittlingmayer would not.

Most of the studies cited by Rowley were done prior to the recent developments in duality theory and computer technology that allow for the econometric estimation of production and cost functions. In estimating such models, it is now possible to take into account problems such as changing factor prices and technological conditions that the earlier studies failed to address sufficiently.

In this paper, we will measure the cost curves of the largest American steel firms to see if the falling cost situation exists. Due to certain measurement problems mentioned below, we will deal only with the short-run, and any conclusions drawn will not necessarily apply to the long-run. But the steel firm's short-run situation could certainly affect its long-run decisions.

A major econometric problem exists, however, in applying cost analysis to firms in industries such as steel because price and quantity are unregulated. The unregulated market output and the total costs of these firms are simultaneously determined; so the chosen outputs are dependent not only on demand conditions but also on the nature of the cost curve. Output is then endogenous not exogenous, and therefore the standard ordinary-least-squares (OLS) technique leads to inconsistent and biased estimators.

Most previous cost-curve analyses have been done for regulated firms such as electric utilities and railroads where output was taken to be exogenous.[1] (See Nerlove 1965; Christensen and Greene 1976; Brown, Caves, and Christensen 1979; and Caves, Christensen, and Swanson 1981.) Even for the regulated firms, however, the simultaneity problem may be present because at some times the regulatory constraint may not be binding (see Joskow 1973). So perhaps an alternative approach may be useful here too. To find this alternative one should view the firm cost function as only one equation embedded in a simultaneous system that includes industry demand, the cost curves of rival firms, and (for oligopolistic firms) equations determining the state of competition. To develop such a complete system may often be impossible due to the lack of data on many relevant variables; so the approach proposed here is to use an instrumental variable for firm output. To find such an instrument, however, we need to examine the general structure of the equation system for the market in which the firm operates.

To implement our study we will use a data sample for the eight largest American firms for the years, 1920-72.[2] In section

---

1 In these industries, firms are legally obligated to provide the output demanded at the presumably exogenously regulated price.

2 These eight firms, in order of usual production size, were U.S. Steel, Bethlehem, Republic Steel, National Steel, Jones & Laughlin, Armco Steel, Youngstown Sheet & Tube, and Inland Steel. All except Inland Steel were multiplant firms.

II the institutional setting of the industry is discussed, and special problems in measuring costs in the industry are analyzed. In section III, the firm cost curves are derived from the production conditions facing the firms. Section IV develops the instrumental variable used for production quantity, and section V gives the estimation results. Section VI concludes the paper by comparing the results with those of other writers.

II. Cost Measurement in the Steel Industry

In the years covered by the study, the American steel industry consisted of eight large firms, usually producing between 70 and 80 percent of industry output, and a large number of fringe firms accounting for the rest. Except for some mergers in the twenties and a slow deterioration in the U.S. Steel share, the market distribution remained quite stable.

Technology changed only incrementally during these years. Larger blast furnaces and superior rolling mills were gradually adopted. For the bulk of the years, the Bessemer furnaces were being replaced by the more efficient open hearth and electric processes. Near the end of the sample period, the greatly superior Basic Oxygen (BOF) steel furnace became prominent in the American market, but in 1970 it accounted for less than half of American production. This was seventeen years after its introduction in this country.

While the structure and technology were relatively stable, the industry and its largest firms experienced considerable growth. Total American steel production grew by 182 percent in this period. The Big Eight firms kept pace with this growth and even increased their market share. In the Depression, however, both industry and firm output were much reduced compared to the 1920's. Consequently, while certain conditions remained quite stable, output by the various steel firms experienced a wider variation than even the growth rates would suggest; so firm costs could be observed under an ample range of output. This makes it possible to measure the cost functions of these firms.

For the greater part of the period, prices were unregulated in steel. Only during World War II, part of the Korean War, and 1972 were there any such regulations. Since the steel companies radically altered their product mix in steel and produced many other products during World War II, the years, 1941 to 1945, were deleted from the sample. Because the Korean War price controls only lasted a short time, those years were left in the sample as was 1972.

One empirical problem is that two steel companies, U.S. Steel and Bethlehem, ran significant other businesses. U.S. Steel made cement, and Bethlehem built ships. Much of U.S. Steel's cement business was derived from its activities in steel, since cement can be made out of blast-furnace slag. But in 1929, U.S. Steel acquired Atlas Cement Co., the production of which cannot be viewed as a byproduct. Methods exist, however, to account for multiproduct outputs. (See Christensen, Caves, and Swanson 1981.) But we were unable to find cement production data for U.S. Steel;

so we could only use a measure of steel production. Even though the demand and cost conditions in cement are not radically different from those in steel, cement-cost movements may still distort the influence of the independent variables, but the direction of the bias is not clear, and it might have changed over time.

In the case of Bethlehem's shipbuilding, a measurement problem exists. The ships built by the company are a heterogeneous group, consisting of almost anything from tugboats to battleships. Therefore, it is difficult to develop an appropriate output measure. The problem is not acute, however, because except for the World War II years (not included in the sample), the firm's ship-building activities were usually an insignificant portion of its total business. Also, since ships are built mostly of steel, the two products share many costs. Consequently no shipbuilding output variable will be included in the Bethlehem Steel cost model.

III. The Derivation of the Steel-Firm Cost Function

First we will derive the cost curves under the assumption that the problem of simultaneity between cost and output has been solved. For each of the large steel firms we have available total cost and output data. Since the eight firms operated under varying conditions as to location, technology, organization, and product mix, a cost function will be estimated for each firm.

To estimate the firm's cost curve, we begin by considering the production function. While steel products are quite numerous, one can still use production in gross tonnage as an output measure, because except for some specialty items, the price per ton and the physical composition of the products are very similar.

In the production of steel, the following inputs account for 90 percent of the cost of steel: coal (C), iron ore (IR), labor (L), steel scrap (SS), and capital (K) [Hekman 1976, p. 14]. Consequently, the steel-production function for firm i can be represented as:

$$q_i = F(C_i,\ IR_i,\ L_i,\ SS_i,\ K_i), \qquad \text{III:1}$$

where q_i = the total tonnage of steel product produced by firm i,

C_i, IR_i, L_i, SS_i, K_i represent the amounts of the various production factors used by firm i.

Past empirical work on the cost function for steel [Hekman 1978] suggests that a Cobb-Douglas function adequately represents the technology of steel production.[1] Two modifications, however, are required for our purposes. First, since our analysis involves a long time period, technological change should be taken into

---

[1] The Cobb-Douglas function is a special case of the transcendental log production function. The transcendental function is less restrictive in that as production increases it is possible to allow the marginal rates of substitution between inputs to vary given unchanging prices. (See Christensen and Green 1976.) Specifically, the transcendental function includes the inputs variables of the Cobb-Douglas function plus cross-products of these variables. Using the transcendental log function, Hekman found that for the steel regions the parameters of the cross products were generally insignificant. Consequently the Cobb-Douglas function can be used to represent the production technology of steel without a significant loss of information.

account. This phenomenon can be accounted for by introducing a time variable in the Cobb-Douglas specification:

$$q_i = AT(t)^{B1}C_i^{B2}IR_i^{B3}L_i^{B4}SS_i^{B5}K_i^{B6}e^u, \qquad \text{III:2}$$

where

T(t) = a time variable representing technological change. This variable might have two components. First, as stated above, technological changes tend to be incremental in this industry; so a continuous time variable would seem appropriate.[1] Second, certain phenomena within firms may have led to discrete shifts in the production functions. Such changes could be represented by dummy variables which can be incorporated into the functions.

The second modification concerns capital. In the short-run, some types of capital cannot be varied, and demand conditions in this industry often dictate an immediately planned output less than the practical maximum allowed for by the amount of available fixed capital.[2] This fact will affect the relationships between costs and outputs. The best way to account for this phenomenon is to consider the fixed capital a separate factor of production; here it will be referred to as K_F. (See Caves, Christensen, and

---

1 For an example of its use, see Christensen, Jorgenson, and Lau [1973].

2 While theoretically there is no upper limit with a Cobb-Douglas function because variable factors could be added ad infinitum, actual input price conditions dictate a practical limit. But here operating under the limit, not above, is the problem being addressed.

Swanson 1979 for a similar treatment.) Therefore, the production function becomes

$$q_i = AT^{B1}C_i^{B2}IR_i^{B3}L_i^{B4}SS_i^{B5}K_i^{B6}K_{Fi}^{B7}e^{B8D}e^{u}. \qquad \text{III:2a}$$

T = the incremental technological change variable,

D = a shift dummy for firm change.

From this production function, we can derive a cost function using duality theory. It can be shown that given certain regularity conditions, the average cost function is the dual of the production function. (See Diewert 1974; Varian 1978, pp. 34-48; and Nerlove 1965, pp. 100-31.)

In converting to the average cost dual, however, a problem exists because K_F, fixed capital, does not vary at any given time. So its price cannot immediately affect this cost figure; but if the amount of K_F changes, the level of average cost will also change. To allow for this situation, a measure of the stock of the fixed capital should be included in the cost function. (See Caves, Christensen, and Swanson 1981 and Lau 1976). But no completely satisfactory measure of the amount of K_F is available; so we resort to a proxy variable. Given the available data, the best one is steel-furnace capacity. So the average cost function would have the following general form:

$$AC_i = AC_i(q_i, CAP_i, T, P_C, P_{IR}, P_L, P_{SS}, P_K, D), \ i = 1,8, \qquad \text{III:3}$$

where AC_i = average cost for firm i; i.e., operating costs minus depreciation, as found in Moody's (1910-76),[1]

CAP_i = steel-furnace capacity for the firm i [American Iron and Steel Institute 1916-80],[2]

T = the technological change variable equals 1 in year 1 and rises to t in year t,

P_C = price index for coal [Bureau of Mines 1960-73],

P_{IR} = price index for iron ore [Iron Age 1916-75],

P_L = price index for labor [Bureau of the Census 1947-73],

P_{SS} = price index for steel scrap [Iron Age 1955-73], and

P_K = price index for capital, taking into account both equipment and interest cost [Department of Commerce 1975, p. 628 and Moody's 1975, p. 246].

(P_K is included in the function because there are types of capital that can be varied.)

Multiplying AC_i by q_i gives us a total cost curve

$$TC_i = AC_i^* \, q_i. \qquad i = 1,8 \qquad \text{III:3a}$$

Given the Cobb-Douglas production function used above and duality theory, this function would have the form below:

$$TC_i = C_0 q_i^{C1} \, CAP_i^{C2} \, T^{C3} \, P_C^{C4} \, P_{IR}^{C5} \, P_L^{C6} \, P_{SS}^{C7} \, P_K^{C8} \, e^{C9D} e^{u}. \qquad \text{III:3b}$$

---

1 This formulation is discussed below.

2 The CAP_i variable was available from American Iron and Steel Institute (1920-60) only up to 1960. For the remaining 12 years, estimates based on the American Iron and Steel Institute Directory (1960-74) and Moody's (1960-75) were used.

Since data are readily available on the values of the above physical inputs used by the steel industry, a weighted average input price index representing the influence of these factor prices can be computed.[1] This allows for greater degrees of freedom and mitigates the multicollinearity problem. Therefore, the input price index is derived as follows:

$$P_I = W_C\ P_C + W_{IR}\ P_{IR} + W_L\ P_L + W_{SS}\ P_{SS},$$

where W_C, W_{IR}, W_L and W_{SS} = the proportion of value-added accounted for by each input.

Capital was not included in the weighted index because there is no good way to measure the amount and value of capital used by a firm at any given time. So taking logs III:3b becomes

$$\ln TC_i = \ln C_0 + C_1 \ln q_i + C_2 \ln CAP_i + C_3 \ln T + C_4 \ln P_I + C_5 \ln P_K + C_6 D + u. \qquad \text{III:4}$$

Our formulation separates the quantity variable, q_i, from capacity, CAP_i. When steel firms change output to adjust for immediately changing demand and competitive conditions, they generally vary production not capacity. Capacity usually changes due to factors outside of short-run conditions. But short-run

---

[1] The sources for this information were the 1919 input-output table for 1920 (Leontief 1951) and the Census of Manufactures for the remaining years (Census 1921-72).

demand conditions could sometimes influence capacity change.[1] This could lead to measurement problems, because CAP_i is influenced by other variables in the cost equation possibly making it endogenous. The CAP_i variable used here, however, is for the beginning of the year, so current conditions would not affect it.

IV. The Instrumental Variable

Equation III:4 will be fitted econometrically for each firm. The usual ordinary-least-squares (OLS) method, however, is an inappropriate estimation technique because q_i is endogenous for unregulated firms. Fortunately using the instrumental-variables procedure can solve this problem (see Johnston 1972, pp. 278-81, and Intriligator 1978, pp. 394-402).

This method consists of finding a variable correlated with q_i but not with the firm cost curve residual term. An appropriate way to construct such an instrumental variable would be to derive a general model for the whole industry, including along with the demand equation, first, the equations for the outputs and costs of individual firms and second, equations specifying the behavior patterns of firm i and its rivals. It is beyond the scope of this paper to estimate such a model, and generally researchers wanting to measure a cost curve do not have the need and/or

---

[1] Gross changes, such as the closing or building of new plants, are determined by long-run plans. On the other hand, replacing wornout equipment and merely operating a plant can lead to incremental technological changes and learning curve effects that can increase capacity.

resources to develop and measure a model for the whole industry. But an equation similar to the reduced form of this model would make a good instrumental variable.

What might be included in such a reduced-form equation? First it would include the set of variables affecting the demand and supply conditions faced by the industry as a whole. Second, a set of variables affecting the particular firm's output and cost should be included. Examples would be the input prices faced by the firm and its capacity. This set would also include variables affecting the expectations about behavior of a firm's competitors.

These expectations variables can be divided into two categories. The first consists of the demand and supply conditions affecting each firm's conjectures about its competitors' actions. If a firm assumes rationality on the part of its rivals, then those conditions can be expected to influence these conjectures. Among them are the firm's assessment of the input cost conditions facing the rivals. Included also should be rival capacity since this would put a limit on their short-run ability to change output. Also, in the second subset would be factors affecting the rivals' desire to respond that might be unconnected with known economic conditions--i.e., psychological assessments. The institutional setting of the industry might also have an influence. Such phenomena are difficult to measure, but variables to represent some of them can be introduced.

These considerations lead to an instrument or reduced form with the following general structure:

$$q_i = q(Y, X, X_i, X_j, \eta) \qquad i = 1, 8 \qquad \text{IV:1}$$

where Y = a vector of variables affecting general demand conditions,

X = a vector of variables affecting general supply conditions,

X_i = a vector of variables affecting the particular cost conditions of firm i,

X_j = a vector of variables affecting the particular cost conditions of its rivals, and

η = a vector of variables (probably institutional and psychological) affecting firm behavior not directly connected with the cost and demand variables.

The two most important exogenous variables affecting the demand for steel are the state of the economy, especially capital spending and manufacturing output, and the price of substitutes.[1] An attractive proxy for the former is the manufacturing-output index developed and compiled by Kendrick [1961 and 1972], GMAN.[2]

Several variables can be used to represent the price of substitutes. The most obvious is the BLS price index for nonferrous metals (PNF), indicating the price of many metals, some of which can be used in place of steel. Since there are other substitutes

---

1 In this paper it will be assumed that steel is a product undifferentiated by firm. It is difficult to ascertain the particular variables that might influence the demand for any given firm's product as opposed to variables influencing the demand for steel in general.

2 One problem is that the change in steel and iron industry output is not netted out. On the other hand, steel and iron account for only about 4 percent of the value-added in manufacturing, and the industry does use its own product; so it is not clear that the adjustment is too important.

(such as concrete), the metal-price variable is not completely representative. On the other hand, economic conditions affecting the unrepresented substitutes would probably impinge on the prices of nonferrous metals. Therefore, the substitution effects are likely to be adequately captured by the metal-price index.

Other phenomena that cannot be represented by continuous variables may have affected steel demand; two seem important. First, the amount of steel used per amount of manufacturing or dollar value of GNP has decreased over time.[1] (See Rowley 1971, pp. 68-71.) This has happened because of the increases in substitutes and the movement of GNP growth, both aggregate and manufacturing, away from steel-using goods. Therefore, developments in the use of steel not accounted for by the above variables may have led to this change. An appropriate continuous proxy for this change, however, is difficult to develop because the exact parameters of the trend are unknown. It is safe, however, to assume that World War II contributed much to this change. (Especially important was the great increase in aluminum production.) Consequently, the best that can be done is to separate the pre-War and post-War periods. Therefore, the following dummy variable will be added to the instrumental-variable equation.

ID = 1 for the years before 1945 and zero afterwards.

---

1 For instance, between 1929 and 1972, real GNP grew 272 percent and manufacturing output grew 395 percent, while apparent steel consumption increased only 141 percent.

The second phenomenon leading a discrete change in the demand curve is the 1930's Depression. So far, changes in manufacturing activity are included in the model, but the construction industry was also an important user of steel (18 percent of the total in 1968). Its activity was especially low during the Depression. In addition, production in the manufacturing sectors that used steel most intensively (autos and capital goods) decreased disproportionately during the Depression. Therefore, a dummy variable for the Depression will also be included.

DEP = 1 for the years 1930-39 and zero otherwise.

The variables affecting supply are divided into the three above categories: X, X_i, and X_j. Technological change (T) should be introduced here because it can affect not only the industry but also the firm and its rivals--maybe to different degrees.

Factor costs would be obvious candidates for inclusion in the equation. These variables affect both total and firm output. Since specific factor prices for each firm are not available, the national factors prices (P_I for the weighted average of coal, iron ore, labor, and scrap prices), and P_K for capital, will be included in the equation.[1] These are factors both for the firm i and its rivals and (therefore) for the entire industry.

---

[1] Needed would be regional factor price data (regional differences result often from transportation costs) and regional firm production data. With these data, weighted factor prices could be developed for each firm. While some regional input prices are available, regional firm data are not generally available, so such weighted averages cannot be calculated. The differences are probably not great. For instance, for much of the period, labor and iron ore had similar prices in all regions.

A specific factor affecting the output of firm i would be its capacity, CAP_i. The capacity of the entire industry would be included in X, and the capacity of the rivals, in X_j. Putting CAP_i, total capacity, and the capacity of i's rivals, CAP_j, into the equation, however, would result in perfect multicollinearity; so CAP_j is left out. In addition, any dummy shift variable would be included in the instrumental variable as a part of X_i.

η consists of other factors influencing the firm's assessment of what other firms would do, such as the institutional and psychological setting. Generally, the variables representing these phenomena cannot be readily measured, but major changes in some aspects of the institutional setting can be detected.

The literature suggests three important institutional developments. Evidence indicates that the demise of the basing-point pricing system in 1948 had a significant impact. Hekman [1978] found that this change led to lower prices, other things equal.[1] A second change seems to have occurred around 1960. The exact reasons for it are difficult to ascertain, but several authorities seemed convinced that a change took place [Mancke 1968, Rippe 1970, and FTC 1977]. The combination of increased imports and market-share deterioration by U.S. Steel apparently led to a more competitive environment.

---

1 This system was in effect in various forms in the steel industry from about 1900 until the FTC cement decision in 1948. (F.T.C. vs. Cement Institute et al., U.S. 683, pp. 712-21 [1948].)

A third watershed would be the 1930's Depression. At least some firms acted more independently during that Depression than they did before and later. (See Weiss 1971, pp. 177-78 and Daugherty, De Chazeau, and Stratton 1937, pp. 667-71.) The economic conditions of the industry may have led to a weakening of any leadership position or collusive scheme among the larger firms. Consequently, the following additional dummies will be included in the instrumental-variable equation along with DEP, the depression dummy:

D_1 = 1 for the period before 1949 when the basing-point price system was in effect, and 0 otherwise,

D_2 = 1 for the period before 1960, and 0 otherwise.

The institutional influences accounted for by the dummies were in many periods operating at the same time. For instance, during the Depression years, the basing-point price system was in effect; so both influences impinged on the steel market.

The reduced form of the output equation then can be given by

$$q_i = q(\mathrm{GMAN, PNF, ID, DEP, T}, P_I, P_K, \mathrm{CAP}_i, \mathrm{CAP}, D_1, D_2, D). \qquad \text{(IV:2)}$$

Since we have reason to believe that IV:2 is nonlinear, a log-log form in which the estimated parameter values generally determine the shape of the curve is used.

$$\ln q_i = \gamma_0 + \gamma_1 \ln GMAN + \gamma_2 \ln PNF + \gamma_3 ID + \gamma_4 DEP + \gamma_5 \ln T + \gamma_6 \ln P_I + \gamma_7 \ln P_K + \gamma_8 \ln CAP_i + \gamma_9 \ln CAP + \gamma_{10} D_1 + \gamma_{11} D_2 + \gamma_{12} D + v. \quad \text{IV:3}$$

Therefore, the predicted value of the left-hand term of IV:3 can be used as an instrument in measuring III:4.

As with equation III:4, equation IV:3 will be estimated for each firm because conditions within any given firm may affect its parameters. These interfirm differences can be expected to influence not only the intercepts of these equations but also the slopes. When we expect these firm-specific conditions to change discretely at a given time, additional dummy variables will be added to the firm equations. Therefore, the cost equations for the eight largest steel firms will be measured using the above-developed instrument.

V. The Results

Equation III:4 was estimated for the eight largest steel companies. Table I shows the results.[1] Before describing them,

---

[1] Since most of the variables in the cost equations are the same across firms, these equations might fall under the category of seemingly unrelated regressions. While the parameters with regard to the individual firms might be different, the underlying system is the same. About this method, however, Johnston [1972, p. 241] states, "The gain in efficiency yielded by the Zellner estimator over the ordinary least squares estimator increases directly with the correlation between the disturbances from the different equations and inversely with the correlation between the different sets of explanatory variables". Three of the variables in the eight equations are identical, the technological variable (T) and (footnote continued)

Table 1.--Total Cost-curve estimates for the "Big Eight" U.S. steel companies, for the periods 1920-40 and 1946-72

Firm	Number of observations	Constant	Steel-ingot production (q)	Steel-ingot capacity (CAP)	Time (T)	Composite input-price index (including prices for coal, iron ore, labor, and scrap steel) (PI)	Price of capital (P_K)	Dummy[3] variable	R^2	F-value	DW
			Regression coefficients for[1] (t-values are in parentheses)								
U.S.[2] Steel	47	6.751	0.695 (19.04)**	0.185 (1.19)	-0.130 (-2.53)++	0.018 (0.31)	0.219 (1.33)		.941	147.76	1.99
Bethlehem Steel[2]	47	3.683	0.727 (10.35)**	0.054 (0.27)	0.062 (0.38)	0.519 (4.05)**	-0.447 (-1.27)		.959	217.52	2.11
Republic[2] Steel	47	1.381	0.840 (14.22)**	0.517 (5.46)++	-0.198 (-1.52)	0.212 (2.44)**	-0.265 (-1.40)	-0.262 (-2.32)+	.994	1212.50	2.04
National Steel	33	8.783	0.686 (6.33)**	-0.544++ (-3.61)	1.114 (4.45)++	-0.056 (-0.51)	0.392 (1.49)		.982	325.98	1.81
Jones & Laughlin	45	6.923	0.615 (13.11)**	-0.145 (-1.23)	0.011 (0.14)	0.384 (6.27)**	0.361 (1.52)	0.332 (4.75)++	.991	787.10	1.82
Armco Steel[2]	47	6.313	0.650 (8.04)**	-0.284 (-1.99)	0.718 (4.23)++	0.258 (3.48)**	0.591 (2.38)**	0.100 (1.16)	.993	1131.95	1.82

Table 1.--Total Cost-curve estimates for the "Big Eight" U.S. steel companies, for the periods 1920-40 and 1946-72 Continued

			Regression coefficients for[1]									
Firm	Number of observations	Constant	Steel-ingot production (q)	Steel-ingot capacity (CAP)	Time (T)	Composite input-price index (including prices for coal, iron ore, labor, and scrap steel) (PI)	Price of capital (P_K)	Dummy[3] variable	R^2	F-value	DW
			(t-values are in parentheses)								
Youngstown Sheet Steel[2]	46	5.507	0.747 (17.82)**	0.107 (0.96)	0.038 (0.51)	0.092 (1.22)	-0.032 (-0.15)		.971	305.73	1.88
Inland[2] Steel	47	3.959	0.873 (17.57)**	-0.295 (-2.20)++	0.462 (3.78)++	0.509 (5.19)**	-0.152 (-0.65)	-0.042 (-0.45)	.993	1039.69	2.18

1/ The dependent variable is sales minus (operating income plus depreciation).

2/ These regressions were adjusted for the presence of autocorrelation by using a generalized least squares method proposed by Harvey (1982).

3/ The dummies were intercept dummies parameterized as follows for Republic and Armco: the dummy equaled zero before 1929 and one for 1929 and after. For Jones & Laughlin it was zero before 1946 and one for 1946 and after, and for Inland it was one before 1935 and zero for 1935 and after.

* Significant at the 95-percent level on a one-tail test.

** Significant at the 99-percent level on a one-tail test.

\+ Significant at the 95-percent level on a two-tail test.

++ Significant at the 99-percent level on a two-tail test.

however, the definition and data sources for the cost variable should be examined because they present a special problem. Our data base is the set of accounting numbers reported in the company annual reports as compiled by Moody's. The cost figure used is sales minus operating income (before taxes and before interest on debt) minus depreciation expense. Depreciation is subtracted out because it is not clear that the usual accounting techniques reflect the actual change in the value of the plants. Capital goods price changes and technological and demand side developments can radically alter the real values of these assets in ways not captured by accounting methods. Therefore, we will only use data which have a more solid basis in facts.[1]

We will first describe the results for the technological and certain dummy variables and then those for the capacity (CAP_i), input-price, and output (q_i) variables. The technological variable (T) may take on either a positive or a negative value.

(footnote continues)

the two input prices. The eight actual output variables are generally highly correlated, 19 of the 28 coefficients being over .90, with 26 over .80. The capacity variables are also highly correlated, 22 being over .90 and 26 over .80. On the other hand, the correlation coefficients between the separate equation residuals are low, only 3 of the 28 being over .60. Therefore while the seemingly unrelated regressions technique was run, it is not reported. The results from this technique along with those from OLS were not particularly different from those of the instrumental variable technique.

[1] When the analysis was done with the depreciation left in the cost, the results were not materially different.

Changes over time in such things as product mix and plant location may compensate or even more than compensate for any efficiency gains due to technological progress. So a two-tail statistical test is used. For three firms--National, Armco, and Inland--the time coefficient is significantly different from zero and positive. For U.S. Steel it is significant and negative.

The remaining four firms had insignificant T-coefficients: positive for Bethlehem, Jones & Laughlin, and Youngstown and negative for Republic. One of the reasons for the positive T-coefficients is that over time certain firms may have moved their product mix in the direction of items requiring more after-finance processing. This occurred at Jones & Laughlin and Inland; they changed their mix from rail-type items to sheets used for autos and appliances. The latter products required greater use of rolling mills. (See in Hogan 1971, the chapters on the firms.)

In cases where an identifiable event affected the nature or policy of a firm during our sample period, the log-log intercept-dummy variable developed above was included in the cost function. This was done in four instances.

(1) In the late 1920's and early 1930's, Republic acquired several other firms. Included in these acquisitions were several plants that Republic was still operating in 1976 (see FTC 1977, p. 55). It is hypothesized that this acquisition program may have changed the cost structure of the firm. The separation year for the dummy was 1929; so for that year and after the dummy variable is valued at 1. When the dummy was tested, it was significantly

less than zero on a two-tail test at the 95-percent level; therefore, this program seems to have lowered Republic's costs.

(2) A dummy variable with 1942 as the separation point was added to the estimated-cost equation for Jones & Laughlin, to account for the acquisition of Otis Steel, with a plant in Cleveland, Ohio.[1] As of 1977, this plant was one of only three fully integrated Jones & Laughlin plants. The dummy variable's coefficient is positive and significant. This may have occurred because, for much of the period, the Otis mill was smaller than the other two plants. Also, the Otis plant may have made more expensive products.

(3) In the late 1920's Armco went through an acquisition program similar to Republic's. It acquired plants in Ashland, Kentucky; Butler, Pennsylvania; and Kansas City. Again 1929 was used as the separation point. Unlike with Republic, its dummy was positive, but it was not significantly different from zero.

(4) In the early 1930's Inland Steel rather suddenly changed much of its product line from heavy steel-beam-like items such as rails to lighter things like sheets for autos and appliances. The product-mix-change dummy using 1935 as the separation point was negative but insignificant.

The input-cost results were strong for the weighted-price variable, P_I, but weak for the price-of-capital variable, P_K. All

---

[1] Since World War II was left out of the sample, in essence the year was 1946.

the P_I coefficients except for National Steel had the predicted sign, and five were highly significant. Of the P_K coefficients, four had the wrong signs, and only one was significantly greater than zero. Perhaps the index used here does not adequately represent the cost of variable capital faced by the firms in the sample.

Some capacity results were strange in that the coefficients were less than zero. They were negative for National, Jones & Laughlin, Armco, and Inland. In the output ranges of the large eight steel companies it is not clear that any economies or diseconomies of scale exist, but one still would not expect negative coefficients. Once output has been taken into account, however, there may be only a loose relationship between capacity and total cost. All the firms except Inland are multiplant; so various plant-size configurations could lead to many different capacity/cost relationships. For instance, over time some firms may have expanded the capacity of mills, making relative low cost steel products. This could lead to the capacity coefficients being negative, perhaps explaining the range of CAP_i coefficients that we have.

The coefficients of the output variables are all significantly larger than zero. Since all the output coefficients are also significantly smaller than one, given the functional form, the steel companies in the sample seem to be operating in a region of falling average costs.

Overall the models used here explained most of the variation in the total cost for the eight largest steel firms. The R^2 ranged from .941 for U.S. Steel to .994 for Republic. As might be expected, the R^2 values were lower for the two firms with significant other businesses, U.S. Steel and Bethlehem.

VI. Implications and Conclusions

The estimates of the cost-output coefficients are significantly less than unity, which is inconsistent with the Rowley hypothesis of rising short-run steel firm cost curves. It does seem incongruous that firms employing different plants often with diverse techniques and capacities do not have rising cost curves. Differing steel product mixes and geographic locations, however, may explain our results. In order to satisfy a heterogeneous geographic and product type demand, American steel firms may have had to use their high cost plants even at low outputs. So as total firm production approaches firm capacity, instead of bringing in their high cost facilities when the capacity of the low cost operations were completely utilized, the companies merely found themselves using all their plants at higher capacities. This would lead to downsloping cost curves like the ones discussed by Bittlingmayer instead of the rising functions of Rowley.

The less than unity coefficients seem also to contradict the results of some earlier works described in Rowley. These writers found short-run total cost curves for steel firms to be linear which indicates a flat instead of downsloping or upsloping marginal and average cost curve. (See Yntema 1940 and Wylie and Ezekiel 1940). On the other hand, the linear function may be a good approximation for the measured curves even though the cost-output elasticity is less than one. To examine this question let us recast equation III:3b, the total cost curve, as follows (the other variables being suppressed):

$$TC_i = C_0(\alpha_i CAP_i)^{C1} CAP_i^{C2}, \qquad i = 1,8 \qquad \text{VI:1}$$

where $\alpha_i CAP_i = q_i$,

$\alpha_i = q_i / CAP_i$, the capacity utilization rate.

Average cost, then, can be derived as follows:

$$AC_i = \alpha_i^{C1-1}\ C_0 CAP_i^{C1+C2-1}. \qquad \text{IV:2}$$

If the firm produces at capacity, α_i^{C1-1} equals one and AC_i collapses to

$$\hat{AC}_i = C_0 CAP_i^{C1+C2-1}. \qquad \text{IV:2a}$$

The term, α_i^{C1-1}, then, is the ratio of average cost at below capacity to average cost at capacity, and the following expression represents the per unit percentage cost penalty for operating at an α capacity utilization rate

$$\text{Penalty} = \alpha^{C1-1} - 1.$$

Table II shows the penalties of operating at various capacity utilization rates for the eight largest American steel firms. Only for Republic and Inland do the cost curves seem even close to flat for the capacity utilization interval between 60 and 90 percent, a range in which most steel firms operated in the years between World War II and the 1970's. Consequently, the linear total cost curve estimates do not seem to be particularly realistic.

Therefore, the marginal cost pricing problem along with the possible consequences for collusion examined by Bittlingmayer does exist for the short-run in the steel industry. On the other hand, the increase in the market share of the smaller "Big Eight" firms indicates that the long-run firm cost curve may not have been down-sloping. Consequently it is possible that price tended to equal long-run marginal cost, and a close-to-efficient outcome may have occurred. To arrive at this result, however, firms must have found a way in the short-run to keep receipts above total costs. Given our cost curve results, this implies a price above not only short-run average but also short-run marginal cost meaning that there may have been a cooperative outcome. The usual profitability of the Big Eight firms during our sample period lends some support to this hypothesis.

Table II

The Penalty Over Full Utilization (Increase in Average Cost) for Operating At The α Capacity Utilization

	Percentage Cost penalty when α equals		
	60%	80%	90%
U.S. Steel	16.9	7.0	3.3
Bethlehem	15.0	6.3	2.9
Republic	8.5	3.6	1.7
National Steel	17.4	7.3	3.4
Jones & Laughlin	21.7	9.0	4.1
Armco	19.6	8.1	3.8
Youngstown Sheet & Tube	13.8	5.8	2.7
Inland Steel	6.7	2.9	1.3

REFERENCES

American Iron and Steel Institute. Annual Statistical Report. Washington, D.C.: American Iron and Steel Institute, 1910-75, various issues.

________. Directory of Iron and Steel Works for the United States and Canada. Washington, D.C.: American Iron and Steel Institute, 1964, 1967, 1970, and 1974.

Baumol, W. J. "Quasi-Optimality: The Price We Must Pay for a Price System." Journal of Political Economy 87(3) (1979):578-99.

Bittlingmayer, G. "Decreasing Average Cost and Competition: A New Look at the Addyston Pipe Case." Journal of Law and Economics 25 (1982):201-29.

Bosworth, B. "Capacity Creation in Basic-Materials Industries." Brookings Papers on Economic Activities 2 (1967).

Brown, R. S.; Caves, D. W.; and Christensen, L. R. "Modelling the Structure of Cost and Production for Multiproduct Firms." Southern Economic Journal 46(1) (1979):256-73.

Caves, D. W.; Christensen, L. R.; and Swanson, J. A. "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74." American Economic Review 71(5) (December 1981):994-1002.

Christensen, L. R., and Greene, W. H. "Economies of Scale in U.S. Electric Power Generation." Journal of Political Economy 84 (4), part I (August 1976):655-76.

Christensen, L. R.; Jorgenson, D. W.; and Lau, L. J. "Transcendental Logarithmic Production Frontiers." Review of Economics and Statistics 55 (February 1973):28-45.

Daugherty, C. R.; De Chazeau, M. G.; and Stratton, S. S. Economics of the Iron and Steel Industry. New York: McGraw-Hill, 1937.

Diewert, W. E. "Applications of Duality Theory." In Frontiers of Quantitative Economics, by M. D. Intriligator and D. A. Kendrick. Amsterdam, Oxford: North Holland Publishing Co., 1974, pp. 105-71.

Federal Trade Commission, Bureau of Economics. The United States Steel Industry and Its International Rivals: Trends and Factors Determining International Competitiveness, 1977.

Harvey, A. C. The Econometric Analysis of Time Series. New York: Halsted Press, 1981.

Hekman, J. S. "An Analysis of the Changing Location of Iron and Steel Production in the Twentieth Century." Ph. D. dissertation, University of Chicago, 1976.

________. "An Analysis of the Changing Location of Iron and Steel Production in the Twentieth Century." American Economic Review 68(1) (March 1978):125-33.

Hogan, W. T. Economic History of the Iron and Steel Industry. 5 Vols. Lexington, Mass.: Lexington Book Co., 1971.

Intriligator, M. D. Econometric Models, Techniques and Applications. Englewood Cliffs, N.J.: Prentice-Hall, 1978.

Iron Age. Vols. 175-213. 1955-73.

Johnston, J. Econometric Methods. New York: McGraw-Hill, 1972.

Joskow, P. L. "Pricing Decisions of Regulated Firms: A Behavioral Approach." Bell Journal of Economics and Management Science 4(1) (1973):118-40.

Kendrick, J. W. Postwar Productivity in the United States. New York: National Bureau of Economic Research, 1973.

________. Productivity Trends in the United States. Princeton: Princeton University Press, 1961.

Kmenta, J. Elements of Econometrics. New York: Macmillan Company, 1971.

Lau, L. J. "A Characterization of the Normalized Restricted Profit Function." Journal of Economic Theory 12 (February 1976):131-63.

Leontief, W. The Structure of the American Economy, 1919-1939. 2d ed. New York: Oxford University, 1951.

Maddala, G. S. Econometrics. New York: McGraw-Hill, 1977.

Mancke, R. "New Determinants of Steel Prices in the U.S.: 1947-65." Journal of Industrial Economics 16(2) (April 1968):147-60.

Moody's Investors Service. Moody's Industrial Manual. New York: Moody's Investors Service, 1910-1975.

Nerlove, M. Estimation and Identification of Cobb-Douglas Production Functions. Chicago: Rand-McNally College Publishing Co., 1965.

Rippe, R. D. "Wages, Prices, and Imports in the American Steel Industry." Review of Economics and Statistics 52 (February 1970):34-46.

Rowley, C. K. Steel and Public Policy. London: McGraw-Hill, 1971.

Tsao, C. S. "Steel Production and Resource Allocation: An Empirical Study." Applied Economics 2 (1970):203-233.

REFERENCES (Continued)

U.S. Department of Commerce, Bureau of the Census. Census of Manufactures, 1919-1972. 1919-75.

U.S. Department of Commerce, Bureau of the Census. Statistical Abstract of the United States: 1980. 101st ed. 1980.

U.S. Department of Commerce, Bureau of Economic Analysis. Survey of Current Business, 1975 Supplement. 1976.

U.S. Department of the Interior, Bureau of Mines. Minerals Yearbook: Fuels. 1960, 1964, 1966, 1970, and 1973.

Varian, H. R. Microeconomic Analysis. New York: W. W. Norton, 1978.

Weiss, L. W. Case Studies in American Industry. New York: John Wiley & Sons, 1971.

Wylie, K. H. and Ezekiel, M. "The Cost Curves for Steel Production." Journal of Political Economy, Vol. 48, No. 6, 1940, pp. 777-821.

Yntema, T. O. "Steel Prices, Volume and Costs." Temporary National Economic Committee Papers, Vol. 1, 1940, pp. 223-323.