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I. Introduction

Oligopolistic markets are common if not ubiquitous, but economists have only put forth a number of competing hypotheses on how firms behave in these situations. The outstanding characteristic of these markets is that any one firm can significantly influence industry output and price. Because of this possibility, a seller in making its price and output decisions has to anticipate how other firms will react when it makes a change. These anticipated reactions are called conjectural variations. Theories of oligopoly behavior must take into account not only demand and factor cost conditions but also conjectural variations.

These variations have been theoretically formulated and in some cases measured.[1] The former studies have found that the conjectural variations should fall into a given range of values. As it happens, the output and price levels generated by the extremes of this conjectural variation range correspond to the outputs and prices of firms operating at the opposite ends of the competitive-monopoly spectrum.[2] Therefore, if firms have conjectural variations (c.v.'s) close to the competitive extreme of this distribution, the hypothesis of competitive behavior cannot

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1 For the theoretical development, see Hicks, 1935, Anderson, 1977, and Kamien and Schwartz, 1981. For empirical studies see Iwata, 1974, Anderson and Kraus, 1978, and Gollop and Roberts, 1980.

2 The empirical studies have generally not contradicted this prediction.

be rejected. On the other hand, the same logic applies to a firm with a c.v. at the monopoly end of the range.

Between these two extremes, one will find conjectural variations corresponding to several proposed solutions to the oligopoly problem such as Cournot, Stackelberg, and limited collusion.[1] Anderson (1977) shows that the first of these theories is of special interest. Its c.v. constitutes a boundary between the range where a firm can be seen as acting independently of its rivals and the range where the firm may be cooperating with them. The former c.v. range is called the adaptive range, while the latter is called the cooperative or matching range.

It should be possible to determine the degree to which an oligopoly firm's behavior is monopolistic or collusive by measuring its conjectural variations and comparing them with those of the above mentioned c.v. ranges. By this method, one may be able to identify industries with serious competitive problems and perhaps test for alternative theories of oligopolistic behavior.

In this paper, conjectural variations in the American steel industry will be measured. Two aspects of this study are of interest. First steel is a large industry and an important part of economy (about 4 percent of manufacturing), and much has been written about it (see Duke et al., 1977, pp. 152-89; Mancke, 1968;

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[1] For the Cournot and competitive solutions, see Fama and Lauffer, 1972; for Stackelberg, see Henderson and Quandt, 1958 and Hicks, 1935; and for limited collusion see Iwata, 1974.

Rippe, 1970; and Parsons and Ray, 1975). Second, this study will employ the technique used by Iwata where the parameters needed to compute the conjectural variation are measured separately and fed into the c.v. formula. More recent studies instead have measured the c.v. as a parameter in a general industry or firm model (Gollop and Roberts 1981). The earlier method used here has the advantage of allowing the c.v. to vary from observation to observation over the sample. This property makes it especially appropriate for dealing with long time periods or periods when markets were undergoing change.

To complete the task set forth above, first the steel industry will be examined to show that the conditions making the c.v. analysis feasible exist. After this examination, the next three sections will derive the formula for the conjectural variation and develop an empirical methodology. Then the hypotheses that the eight largest steel firms had conjectural variations consistent with either perfectly competitive or monopolistic behavior will be tested. Also a one-tail test (as explained below) will be made for the hypothesis of Cournot behavior to see whether the firms' c.v.'s lie in the adaptive or cooperative ranges. Last, a sensitivity analysis will assess the effect of measurement error in the parameters of the c.v. formula.

II. The Steel Industry

In order to calculate company conjectural variations and make useful tests with them, certain conditions must be present.

First, the market should be structurally oligopolistic, and second, the data needed to calculate the model must be available. Third an industry must have a degree of stability in demand composition and production technology for the conjectural variations to be measured from the actual data.

In the U.S. steel industry, these conditions were present in the period from about 1920 to the early 1970's, and data are available for 1920-72.[1] While many firms operated in this sector the bulk of the output was produced by a few firms. (For output data, see American Iron and Steel Institute, 1910-75.) In 1968, the two largest firms had over 40 percent of the industry, the largest four firms had over 54 percent, and the largest eight, over 75 percent. Historically, the degree of concentration in the industry has also been high; in 1920, the corresponding shares were 51.3, 58.7, and 63.8 percent. Given these concentration levels, it seems plausible that at least some of the larger steel firms took into account the output and price reactions of other firms. Therefore, measuring conjectural variations for firms in this industry is likely to shed light on oligopolistic behavior.

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[1] In the later parts of the 1970's, much of the accounting data needed for the study became unavailable due to mergers and steel firm diversification. Another problem was the presence of import quotas; this started in 1969 which was in our sample, but at that time imports were less than 20 percent of the industry, and these controls probably did not significantly change the behavior of the domestic firms. Also, the World War II years, 1941-45, were left out of the sample; at that time one could expect quite different firm behavior because of price controls and perhaps a change in firm motivation due to the war effort. The steel firms also engaged in a much wider range of activities than in peacetime.

As shown below, a formula for conjectural variations can be derived that contains either data-variables that are normally collected for most markets or parameters that can be efficiently estimated. In steel, sufficient data to compute the conjectural variations exist over a long time period for both the whole industry and a good sample of the firms. The largest steel companies have been around a long time, and their production and accounting data go back a long way (see Moody's 1910-75). Historically, steel companies have been specialist firms. Until quite recently, they had not been very diversified, and they had not been bought by conglomerate firms. Consequently, the firms in question were essentially organizations engaged in the same activity and the same business over a long time period. As a result, we have available not only the variables directly used in the c.v. computation but also the numbers needed to estimate the necessary parameters.

Estimates of conjectural variations that reflect the firms' actual conjectures can only be made for industries where on a year to year basis, firms can readily predict their own output and that of their rivals. It has been shown that in the short run the supply conditions in steel tend to be stable while demand conditions fluctuate with the business cycle (see Rogers, 1983a, Chapter IV). Demand composition and basic supply technology also have been subject to only slow change. Therefore output changes can be predicted, and we can make an accurate estimate of conjectural variations even though we do not have direct evidence on the firm decisionmakers' planning and motivations.

III. The Basic Model

Our model assumes an oligopolistic industry with n firms and no firm-specific product differentiation.[1] Given profit maximization, each firm has the following objective function:

$$\pi_i = P(Q)q_i - TC_i, \qquad i = 1, n \qquad \text{III:1}$$

where

P = price = $P(Q)$, the inverse-demand function,

$Q = \Sigma q_i$,

q_i = quantity produced by firm i, and

$TC_i = TC_i(q_i)$ the total cost function for firm i.

It is assumed here that each firm varies its output to achieve its goal. Therefore, for firm i, the perceived marginal profit function or the first derivative of profit with respect to output would be as follows:

$$\pi_i' = P + q_i \frac{\partial P}{\partial q_i} - MC_i, \qquad i = 1, n \qquad \text{III:2}$$

where $\frac{\partial P}{\partial q_i}$ = the derivative of price with respect to firm i's output,

and

MC_i = the marginal cost of firm i.

[1] It might be argued that due to varying product mix and different geographic locations, this assumption does not hold in steel. But the "Big Eight" firms had very similar product mixes, and their plants were located in approximately the same geographic area. See Rogers 1983a, chapter IV.

Following Iwata (1974) and Hicks (1935) this function can be expressed as follows:

$$\pi_i' = P + q_i P'(1 + \delta_i) - MC_i = 0, \qquad i = 1, n \qquad \text{III:3}$$

where $P' = \frac{\partial P}{\partial Q}$, and

$\delta_i = \sum_{j \neq i} \frac{\partial q_j}{\partial q_i}$, the change in the rest of the industry's output in reaction to a change in the original firm's output.

What the firm thinks the rest of industry will do determines its behavior. If the empirical estimate of δ_i takes on a value consistent with given behavior, then a strong argument exists in favor of the hypothesis that this behavior is being followed. To test various hypotheses, we will show which values of δ_i are consistent with what types of behavior.

In order to readily use our data base, the marginal profit function can be altered to the following form [Iwata 1974]:

$$\pi_i' = P + \frac{q_i}{Q} \frac{P}{e} (1 + \delta_i) - MC_i = 0, \qquad 1 = i, n, \qquad \text{III:3a}$$

where $e = \frac{\partial Q}{\partial P} \frac{P}{Q}$, the elasticity of demand.

So we can solve for δ_i,

$$\delta_i = e \frac{Q}{q_i} \frac{(MC_i - P)}{P} - 1, \qquad i = 1, n. \qquad \text{III:4}$$

Using equation III:3, consider what the various behavior patterns such as the competitive, Cournot, and monopolistic imply for the c.v. value. A competitive firm sets its output at the point where price equals marginal cost. In this case the conjectural variation would be -1 as described in Fama and Laffer [1972] and Anderson [1977]. Under the Cournot hypothesis, a firm sets its output on the assumption that other firms do not respond; therefore the conjectural variation will be zero.

Anderson [1977] shows what c.v. values imply collusive behavior. Essentially firm behavior is apt to be collusive when the conjectural variations are greater than zero. He calls this situation matching behavior.

It may be possible for firms in some industries to collude so well that they can arrive at a price and output that maximizes total industry profits. This will be called Patinkin behavior because under it all the firm marginal costs are equal as shown by Patinkin (1947). In the Patinkin situation, the c.v. value, then, would be as follows:

$$\delta_i = \frac{Q}{q_i} - 1. \qquad i = 1, n.$$ [1]

Therefore a conjectural variation equal to the inverse of the market share minus one implies industry profit maximization.

From a simplistic social-welfare viewpoint, perfect competition and Patinkin collusion represent extremes, the first generally being considered the best outcome and the second, the worst.

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[1] One can see how the industry monopoly solution is arrived at by substituting this formula into III:3a. Since δ_i is greater than zero, this outcome also falls under the category of matching behavior.

For the seller, perfect competition is the situation where it has the least control, while Patinkin collusion would give it the greatest control.[1] While these extremes have normative importance, they are unlikely to be observed here. The steel industry is highly concentrated mitigating against minus one c.v.'s. On the other hand, there are quite a few large firms (eight) which lowers the likelihood of Patinkin behavior.

By contrast, matching behavior is a range of intermediate positions, which may have empirical support and policy significance. It may be possible for firms to imperfectly collude. On the other hand, collusion may be so difficult that firms would essentially act independently. The latter course would imply an "adaptive" c.v. below zero but not necessarily close to -1. Since real costs often dictate a small numbers market, such behavior may be the best that can be expected. Perhaps, antitrust actions such as the prevention of collusion could force firms to change from matching to adaptive behavior possibly leading to better market outcomes. Consequently whether firm c.v.'s are in the matching range or not may be an excellent guide for allocating scarce antitrust resources. Therefore, the tests for these intermediate types of behavior which indicate the relative positions of

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[1] The configuration of seller costs could alter these conclusions. For instance, a higher cost firm may not want to yield market share to others where such a concession would be necessary for the Patinkin solution.

the firms in the market-control continuum will have policy implications.

The Cournot point, the dividing line between adaptive and matching behavior, will also be tested because first it is a traditional oligopoly theory, and second many studies of small numbers markets implicitly assume such behavior.

To summarize the following behavior patterns imply the below c.v. values:

Competitive	$\delta_i = -1$	III:5
Cournot	$\delta_i = 0$	III:6
Matching	$\delta_i > 0$	III:7
Perfectly collusive or Patinkin	$\delta_i = \frac{Q}{q_i} - 1.$	III:8

In order to test for these values, an empirical analogue for III:4 will be developed, and variances about it, computed.

IV. Estimates for Demand Elasticity and Marginal Cost

Testing our theories requires estimates of two values: elasticity of demand and firm marginal cost. To find the former, a demand curve for the steel industry will be estimated, and for the latter, firm cost curves will be measured.

To estimate demand elasticity, we use a simultaneous equation supply-and-demand model, and thus we must consider the variables that can be expected to influence both the demand and supply of steel. The two most important factors affecting demand are the level of manufacturing activity and the price of substitutes (respectively called here GMAN and PNF). To account for discrete changes in other factors influencing demand, dummy variables are added for the depression (1930-39) and for the post World War II years where macro events caused radical changes (probably decreases) in the other things equal demand for steel (see Rogers 1983a). A constant elasticity log-log demand curve is used for our estimation,[1]

$$\ln Q_d = \ln b_0 + f \ln P + b_1 \ln GMAN + b_2 \ln PNF + b_3 ID + b_4 DEP + v, \qquad IV:1$$

where

Q_d = the amount of steel consumed in the U.S. for any year; i.e., apparent consumption i.e., U.S. production + U.S. imports - U.S. exports (American Iron and Steel Institute (1910-75),

f = demand elasticity,

P = steel price index, as compiled by the American Metals Market, 1974,

GMAN = the level of manufacturing activity (computed by Kendrick 1961 and 1973),

PNF = the BLS index of nonferrous metal prices,

ID = 1 before World War II and zero after 1945,

DEP = 1 for 1930-39 and zero otherwise.

The supply relationship can be derived from the industry production function by duality theory. (See Diewert 1974, and Varian 1978, pp. 34-49). For the steel industry, the Cobb-Douglas formula is a plausible approximation for the production function

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1 The hypothesis that demand elasticity may have changed over the sample, 1920-72, was tested, but the observed changes were insignificant (see Rogers, 1983a).

(see Hekman, 1976 and 1978). From this function a marginal cost function can be derived as shown in Rogers 1982a. It is a function of quantity, technological change variables, industry capacity, and input prices.

$$\ln MC = \ln C_0 + C_1 \ln Q + C_2 \ln T + C_3 \ln CAP + C_4 \ln P_C + C_5 \ln P_{IR} + C_6 \ln P_L + C_7 \ln P_{SS} + C_8 \ln P_K + u \qquad \text{IV:2}$$

where T = a variable to account for technological change, valued at 1 in the first year of the sample, and rising to t in the t^{th} year,[1]

CAP = steel furnace capacity for the industry [American Iron and Steel Institute 1916-60, and Bosworth 1976],

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 [Bureau of the Census 1976 and Moody's 1975].

Because steel is an oligopolistic industry, price may not equal marginal cost.[2] Therefore, to reflect any markup of the price over marginal cost, we related the two as follows:

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1 In steel, technological change was gradual, therefore a counter-type variable seems most appropriate.

2 In these industries, the traditional supply function, which is independent of demand conditions, does not really exist. In this paper supply refers to the amount supplied at any given price under a given set of demand, market structure, and behavior conditions. This concept has often been called a quasi-supply function.

$$P = (1+m)MC, \qquad \text{IV:3}$$

where m = the percentage markup divided by 100.

This equation can be estimated by substituting IV:2 into IV:3, like so:

$$\ln P = \ln(1+m) + \ln MC. \qquad \text{IV:3a}$$

The markup is assumed to depend on steel firm conduct.[1] To model m, we identify institutional developments during the sample period that would have led to radical changes in steel-firm conduct. The literature suggests three such changes: the demise of the basing-point pricing system in 1948, the 1930's Depression, and a possible conduct change around 1960. Hekman [1978] found that the basing-point pricing system led to higher prices, other things equal.[2]

Evidence also indicates that at least some firms acted more independently during the depression in the 1930's than they did at any other time. (See Daugherty, De Chazeau, and Stratton 1937, pp. 667-71.) The economic conditions of the industry may have led to a weakening of any collusive scheme among the larger firms. Consequently, we will hypothesize that the markup determining mechanism could have been considerably different during the 1930's.

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[1] The mark-up incidentally is closely related to conjectural variations. Different sets of firm c.v.'s will lead to different industry mark-ups.

[2] 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 change seems to have occurred around 1960, but the reasons for it are difficult to ascertain even though several authorities conclude that it was real [see Mancke 1968, Rippe 1970, and Duke et al., 1977]. The combination of increased imports and the market-share deterioration of U.S. Steel apparently led to a more competitive environment.

Since the markup of price over marginal cost (m in IV:3) is embedded in the price equation constant, a way to parameterize the changes in expected markup would be to add intercept-dummies for the times when the institutional environment changed. So the following supply equation is hypothesized:

$$\ln P = \ln C_{00} + C_1 \ln Q + C_2 \ln T + C_3 \ln CAP + C_4 \ln P_C + C_5 \ln P_{IR}$$
$$+ C_6 \ln P_L + C_7 P_{SS} + C_8 \ln P_K + C_9 D_1$$
$$+ C_{10} D_2 + C_{11} DEP + u \qquad \text{IV:4}$$

where $\ln C_{00} = \ln(1+m) + \ln C_0$

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.[1]

Using the supply and demand model consisting of equations IV:1 and IV:4, the demand for steel can be estimated by Two Stage Least Squares. The reduced form equation for price is

$$\ln P = \gamma_0 + \gamma_1 \ln GMAN + \gamma_2 \ln PNF + \gamma_3 ID + \gamma_4 \ln T + \gamma_5 \ln CAP + \gamma_6 \ln P_C$$
$$+ \gamma_7 \ln P_{IR} + \gamma_8 \ln P_L + \gamma_9 \ln P_{SS} + \gamma_{10} \ln P_K$$
$$+ \gamma_{11} D_1 + \gamma_{12} D_2 + \gamma_{13} DEP + w. \qquad \text{IV:5}$$

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1 DEP defined above captures the effect of the depression.

When equation IV:1 was estimated, predicted and plausible values were arrived at for all the parameters with the coefficients for P, GMAN, PNF, and ID being significantly different from zero.[1] The elasticity of demand estimate is -0.738 with a standard deviation of 0.195 which is consistent with other demand estimates (Rowley 1971).

Since conjectural variations will only be estimated for the eight largest firms, an estimate of the supply curve for the rest of the industry is necessary. Therefore the relationship between price and fringe output (including that of offshore firms exporting to the United States) has to be considered.

We assume that each large firm acts as if it belonged to a dominant group. The firm will, then, subtract the expected output of the fringe from the industry demand curve to arrive at a demand curve for itself and the other seven large firms.

$$Q_L = Q - Q_F, \qquad \text{IV:6}$$

where

Q_L = the total output of the large firms,

Q_F = the total output of the fringe firms.

Here it will be assumed that the fringe as a whole behaves competitively. The other steel firms in the American market were

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1 The equation's R^2 was 0.970 with an F value of 305.65. The expected signs for GMAN, PNF, ID, and DEP were respectively positive, positive, positive, and negative. Due to the presence of secret price discounting, the transactions prices are often unobserved. So an adjustment was made. To see how this was done, see Rogers 1983a.

considerably smaller than the "Big Eight." The ninth was usually about half the size of the eighth. Therefore the fringe essentially produces at the point where price equals its marginal cost. This function can be expected to be influenced by input prices and technological factors,

$$P = MC_F(Q_F, TP, PI), \qquad \text{IV:7}$$

where

TP = the vector of nonprice exogenous variables for the fringe as shown in equation IV:4,

PI = the vector of input prices.

Taking the inverse of this function, one arrives at

$$Q_F = MC^{-1}(P, TP, PI).^{1} \qquad \text{IV:8}$$

Substituting in IV:6, one then can find the demand faced by the Big Eight,

$$Q_L = Q(P,Y) - MC^{-1}(P, TP, PI), \qquad \text{IV:9}$$

where

Q(.) = the industry demand function,

Y = the vector of exogenous variables that enter into the demand function.

The equation for this residual demand function given log-log industry demand and fringe supply functions is as follows (variables other than P for these functions being suppressed):

$$Q_L = b_0P^f - g_0P^{g1}, \qquad \text{IV:9a}$$

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[1] The exact form (log-log) of this function is developed in Rogers, 1983a, chapter V.

where b_0, f = demand equation parameters, the latter being the elasticity of demand, and

g_0, g_1 = fringe supply function parameters.

From this function the Big Eight demand elasticity function can be derived,

$$e_L = \frac{1}{Q_L} (fQ - g_1 Q_F). \qquad \text{IV:10}$$

Rogers (1983a) found that g_1 is not significantly different from zero. So it is likely that price does not affect fringe production (at least in the short run).[1] Therefore, a vertical fringe-supply curve is assumed; so

$$e_L = \frac{1}{Q_L} fQ. \qquad \text{IV:11}$$

In order to use the e_L for testing purposes, we must estimate a variance for e_L which has the following form:

$$\text{Var } \hat{e}_L = \left(\frac{Q}{Q_L}\right)^2 \text{Var } \hat{f}. \qquad \text{IV:12}$$

Therefore in the marginal-profit functions for the large firms, Q_L and its elasticity, e_L, will replace Q and e, as follows:

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[1] The data observation is for the year; so the c.v. refers to the change in output by other firms expected within the given year. So it is short run behavior with respect to a year that we are analyzing.

$$P + \frac{Pq_i}{e_L Q_L}(1 + \delta_i) - MC_i = 0.$$ [1] IV:13

In order to measure marginal cost, a total cost function for each of the large steel firms was derived. We have available total cost and output data. The eight firms for which conjectural variations will be estimated operated under varying conditions as to location, technology, organization, and product mix. Therefore, a cost function will be estimated for each.

To find this function, duality theories can be used. For each firm a Cobb-Douglas production function was assumed, and the following cost function posited:

$$TC_i = C_0 q_i^{C1} T^{C2} CAP_i^{C3} P_C^{C4} P_{IR}^{C5} P_L^{C6} P_{SS}^{C7} P_K^{C8} e^u,$$

or $TC_i = C_{Ai} q_i^{C1}, \qquad i = 1, 8,$ IV:14

where

$$C_{Ai} = C_0 T^{C2} CAP_i^{C3} P_C^{C4} P_{IR}^{C5} P_L^{C6} P_{SS}^{C7} P_K^{C8} e^u$$

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[1] One unavoidable data problem should be pointed out. We have estimates of the demand function for steel consumed in the United States and the U.S. fringe-supply equation--the latter being the sum of small-firm production and imports (see Rogers, 1983a, chapter V). But some of the U.S.-produced steel was exported. Unfortunately, data do not exist on which companies exported steel, and consequently the available market share data for both the Big Eight and the domestic fringe consist only of production in, not shipments to, the U.S. market. In order to arrive at a consistent number, we will assume that all U.S. exports were made by the Big Eight. For the early part of the sample this is quite defensible, because the major steel exporter was U.S. Steel, but for later years it is questionable. On the other hand, the importance of exports declined in the later part of the sample period.

with

u = the exponential residual term

CAP_i = capacity of firm i.

This function is fitted econometrically for each firm in Rogers 1983b. Since the ordinary least squares (OLS) method is inappropriate because of simultaneity between TC_i and q_i, an instrumental variables procedure is employed.[1] The marginal of this function, then, is:

$$MC_i = C_1 C_{Ai} q_i^{C_1 - 1}, \quad i = 1, 8, \qquad \text{IV:15}$$

or

$$MC_i = \frac{C_1 TC_i}{q_i}, \quad i = 1, 8. \qquad \text{IV:15a}$$

Table I shows the output cost elasticities of the "Big Steel" firms. As expected all are significantly greater than zero. On the other hand, all of the coefficients were significantly less than one. Consequently when capacity is taken into account, the average cost curves are apparently downsloping. Earlier writers have concluded that the curves were either flat or upsloping, but their evidence is either intuitive or flawed (see Rowley 1971, pp. 43-49). On the other hand, perhaps our estimates using accounting data do not take all the costs into consideration. Consequently it may be desirable to make several calculations for

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1 The instrumental variable was the predicted value of a regression of q_i on the exogenous variables in the supply and demand model plus certain firm specific variables such as capacity.

Table I

The Shortrun Coefficients of Steel Output with Respect to Firms' Total Cost for the "Big Eight" Steel Companies for 1920-40 and 1946-72

	Coefficient for output C_1	Standard deviation of the coefficient
U.S. Steel	0.695	0.037
Bethlehem	0.727	0.070
Republic	0.840	0.059
National Steel	0.686	0.108
Jones & Laughlin	0.615	0.047
Armco	0.650	0.081
Youngstown Sheet & Tube	0.747	0.042
Inland Steel	0.873	0.050

the conjectural variation, each assuming a different value for C_1. Then some sensitivity analysis can be performed.

V. Conjectural Variation Estimation Methodology

For each firm we will measure the conjectural variation taking into account the fringe by assuming that it does not respond immediately to price with the c.v. formula IV:13,

$$\delta_{it} = e_{Lt} \frac{Q_{Lt}}{q_{it}} \frac{(MC_{it} - P_t)}{P_t} - 1 \qquad i = 1, 8. \qquad \text{V:1a}$$

Taking advantage of the Cobb-Douglas cost function, the c.v. formula can be put into the following empirical form using the available data:

$$\delta_{it} = e_{Lt} \frac{Q_{Lt}}{q_{it}} \frac{(C_{1i}\ TC_{it} - P_t q_{it})}{P_t q_{it}} -1 \qquad i = 1, 8, \qquad \text{V:1b}$$

where C_{1i} = the total cost/output coefficient of firm i,

$P_t q_{it}$ = total revenue of firm i.

The next step is to find the variance for this expression. Here there are two stochastic variables: e_{Lt} from equation IV:11 and C_{1i} from Table I.

Simplifying our problem, let us eliminate the -1 on the right hand side of IV:1b,

$$\delta_{iit} = 1 + \delta_{it}, \qquad i = 1, 8. \qquad \text{V:2}$$

To find the variance of the estimated value, $\hat{\delta}_{iit}$, about the true value, δ_{iit}, we use a Taylor series. It is derived from the deviations of the measured stochastic variables about their true values. This method gives us an approximate value for the deviation of $\hat{\delta}_{iit}$ from δ_{iit}. Therefore,

$$\hat{\delta}_{iit} - \delta_{iit} = \delta_e (\hat{e}_{Lt} - e_{Lt}) + \delta_C(\hat{C}_{1i} - C_{1i}) \quad i = 1, 8, \qquad V:3$$

where δ_e, δ_C, = the derivatives of δ_{iit} with respect to e_{Lt} and C_{1i},

$\hat{e}_{Lt}$, $\hat{C}_{1i}$ = the measured values of e_{Lt} and C_{1i} and

e_{Lt}, C_{1i} = the true values.

When this figure is squared, we have an estimate of the variance of δ_{iit},

$$\text{Var } \hat{\delta}_{iit} = \delta_e^2 \text{ Var } \hat{e}_{Lt} + \delta_C^2 \text{ Var } \hat{C}_{1i} + 2\delta_e\delta_C \text{Cov } (\hat{e}, \hat{C}_{1i}).$$ [1]

The measured demand elasticity is found when the demand function for Big Eight steel is estimated. The variance of this parameter is a function of the error of the estimate for the demand equation. The variance of C_{1i}, on the other hand, is determined by the cost conditions for steel firm i that were left out of the cost estimating equation--for instance, some aspects of technology

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1 See Klein [1953], p. 258, and Kmenta [1971], pp. 443-44, for illustrations of similar applications of this procedure.

and input prices. For a given firm, the conditions not accounted for in the statistical model of MC_i are probably only remotely connected to the relevant variables missing from the demand function. Consequently, the covariance of $\hat{e}_{Lt}$ and $\hat{C}_{1i}$ is assumed to be zero. Therefore, the variance for $\hat{\delta}_{iit}$ can be approximated by the following equation:

$$\text{Var } \hat{\delta}_{iit} = \delta_e^2 \text{ Var } \hat{e}_{Lt} + \delta_C^2 \text{ Var } \hat{C}_{1i}. \qquad \text{V:4}$$

From this, a standard deviation can be found.[1] Since $\hat{e}_{Lt}$ and $\hat{C}_{1i}$ have at least asymptotically normal distributions, the $\hat{\delta}_{iit}$ can be viewed as normally distributed. So the tests shown in equations III:5-III:8 can be made to see whether the c.v., $\hat{\delta}_{it}$, is significantly different from the values suggested by certain types of oligopoly behavior.[2]

VI. The Results

In this section, we will confront our results with the four behavior hypotheses developed above under the assumption that the measured output cost elasticities are accurate.

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[1] The derivatives, δ_e and δ_C, are respectively

$$\delta_e = \frac{Q_{Lt}}{q_{it}} \frac{(C_{1i}\ TC_{it} - P_t q_{it})}{P_t q_{it}}$$

and

$$\delta_C = e_L \frac{Q_{Lt}}{q_{it}} \frac{TC_{it}}{P_t q_{it}} .$$

[2] Because δ_{it} equals δ_{iit} -1, δ_{it} and δ_{iit} have the same variance.

Table II gives the average c.v.'s for all the year of the sample, along with the average standard deviations.[1] Given our formulations for the c.v.'s and their variances (equations V:1b and V:4), tests for the hypothesized behavior patterns can be made for each year. For the competitive, Cournot, and Patinkin theories, we use a t-test for the hypothesis that the conjectural variation for each year was significantly different from the value implied by the given type of behavior.[2] While a significant difference implies a high probability of the hypothesis not being true, insignificant results mean only that the c.v. value was consistent with the given behavioral hypothesis.

To test for matching behavior we employ a t-test to see if the c.v. is significantly greater than zero. Again a c.v. in the acceptance range does not mean that the behavior was necessarily occurring. Rather it means only that the c.v. value is consistent with the hypothesis in question.

Table III shows the number of years in the sample for which the c.v. values were consistent with each hypothesis. For all the

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[1] The average standard deviation is found by summing up the variances for the various years, dividing them by the number of year-observations, and calculating the square root.

[2] For the competitive and Patinkin hypotheses, one-tail tests are used. These behavior patterns are extremes. A two-tail test is used for the Cournot hypothesis because it occupies an intermediate position. Matching behavior requires a one-tail test because it merely implies c.v.'s of greater value than zero. In this sample there are observations where the one-tail tests for matching behavior and the two-tail tests for the Cournot theory are inconsistent.

Table II

The Average Conjectural Variations for the "Big Eight" Steel Companies for 1920-40 and 1946-72, and t-Test Values for the Hypotheses that the Calculated Values Differed from the Expected Values for Competitive, Cournot, and Patinkin Behavior Under the Assumption that C_1 Equals the Measured Value

			t-Values for		
Firm	Average Conjectural Variation	Standard Deviation	Competitive Behavior	Cournot Behavior	Patinkin Collusion
U.S. Steel	0.016	0.288	3.53*	0.06	-4.80*
Bethlehem	1.371	0.767	3.09*	1.79*	-4.41*
Republic	2.979	1.668	2.39*	1.79*	-6.22*
National	5.221	2.061	3.02*	2.53*+	-4.08*
Jones & Laughlin[1]	5.869	1.917	3.58*	3.06*+	-3.96*
Armco	10.499	4.426	2.59*	2.37*+	-3.13*
Youngstown[1]	5.657	1.899	3.51*	2.98*+	-6.03*
Inland	4.617	1.755	3.20*	2.63*+	-7.81*

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

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

1 Now part of the LTV Corporation.

Table III

The Number of Years for Which the Conjectural Variations Are Consistent With Various Behavior Hypotheses Under the Assumption that C_1 Equals the Measured Value

	The Number of Years When the Conjectural Variation was Consistent with[1]			
Firms[2]	Competitive Behavior	Cournot Behavior	Matching Behavior	Patinkin Collusion
U.S. Steel	0(48)	46(2)	0(48)	0(48)
Bethlehem	0(48)	37(11)	32(16)	0(48)
Republic	1(47)	24(24)	39(9)	0(48)
National	0(33)	0(33)	33(0)	0(33)
Jones & Laughlin[3]	0(45)	0(45)	45(0)	0(45)
Armco	0(48)	0(48)	48(0)	0(48)
Youngstown[3]	0(47)	0(47)	47(0)	0(47)
Inland	0(48)	0(48)	48(0)	0(48)

[1] The conjectural variation is considered consistent with given behavior if its value is not significantly different from the postulated value at the 5-percent level.

[2] The number of years when the behavior is not considered consistent with the named behavior is in parentheses.

[3] Now part of LTV Corporation.

firms, the hypothesis of perfectly competitive behavior can be rejected for the great bulk of the sample. In no year could the hypothesis be accepted for U.S. Steel, Bethlehem, National, Jones & Laughlin, Armco, Youngstown and Inland. For Republic, the hypothesis cannot be rejected in only one year, 1921--a depressed year. Conspicuous about these results is that for the given firms they hold over most of the sample.

On the other hand, when the Cournot hypothesis is examined, the results for some firms do not show such a consistency across time. For U.S. Steel, however, the bulk of the yearly c.v.'s are not significantly different from zero implying that Cournot behavior cannot be rejected. Bethlehem and Republic seem to be the intermediate cases. For Bethlehem, the Cournot hypothesis is supported in 37 of the 48 years, and for Republic there is evidence in favor of the Cournot hypothesis for half of the sample (24 years). In the case of Bethlehem, the Cournot hypothesis can only be rejected for some years in the 1920's and 30's. On the other hand, it was not only for the 1920's but also for most of the 1950's and 1960's that the Republic c.v.'s were significantly different from zero on a two-tail test. For the remainder of the firms, the Cournot hypothesis can be rejected for the whole of the sample.

Since the test for the matching behavior implies c.v.'s greater than zero, one uses a one-tail test instead of the two-tail test. Except for U.S. Steel, generally the firm c.v.'s are greater than zero. For Bethlehem, the one-tail test often contradicts the two-tail test; zero c.v.'s can be rejected in favor of matching behavior for 32 years. For 21 of those years, however, Cournot behavior cannot be rejected on a two-tail test. For Republic using a one-tail test led to the rejection of Cournot in favor of matching behavior in 39 years of the sample. Consequently some skepticism must be exercised in attributing matching behavior to these firms for some years. Generally these consisted of the 1920's and the years between 1948 and 1969. For National, Jones & Laughlin, Armco, Youngstown, and Inland, the one- and two-tail tests were generally consistent with matching behavior for the entirety of the period. The Patinkin collusion hypothesis can be rejected for all of the sample for all the firms.

By taking an average of the c.v.'s for each firm over the sample, we can get a summary view of the results. Table II shows the mean and average standard deviation of the yearly c.v.'s for each firm. All are greater than zero, the largest being that of Armco. Consistent with the yearly results, the average c.v.'s are significantly different from -1, competitive behavior, for all firms. The results on the averages show that for five firms, Cournot behavior can be rejected on a two-tail test. As stated above, for matching behavior a positive one-tail test for the zero c.v. is used. For the average c.v., the results are consistent with matching behavior for all firms except U.S. Steel. As with the yearly results, the Patinkin hypothesis can be rejected for all the firms.

To summarize, in most years, Cournot behavior cannot be rejected for U.S. Steel and Bethlehem. The matching hypothesis is generally consistent with the results for the other six firms, and for no firms are the measurements generally consistent with the competitive or Patinkin theories. With the yearly results, the c.v.'s generally fall into the same acceptance or rejection intervals for the great bulk of the sample for all firms except Bethlehem and Republic with the Cournot theory.

VII. Sensitivity Analysis

Because of measurement problems in the cost equations, a sensitivity analysis will be undertaken for variations in the cost-output elasticities.[1] The major sources for these variations are first the stochastic nature of the cost estimation procedure (multiple regression) and second possible errors in the total cost variable used. It is not clear that the accounting measure we used to represent short-run cost is appropriate.

The cost figure used is sales minus operating income (before taxes and before interest on debt) minus depreciation. This differs from the normally presented concept of cost, sales minus operating income, in that depreciation expense has been taken

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[1] Alternative models of demand result in elasticities (from about -0.69 to -0.75) not significantly different from the one used here. (See Rogers 1983c). So we will not test for varying demand elasticities.

out.[1] Accounting depreciation computations often do not reflect the real decline in asset value. But assets do decline in value, so at least part of the depreciation expense might be included in the cost figure.

To see the possible extent of this problem, we begin by examining the ratio of depreciation expense to our total cost figure. This ratio plus one shows the ratio of the maximum possible appropriate total cost figure to the cost figure used. The averages over the sample for these total figures, called henceforth depreciation ratios, are as follows: 1.07 for U.S. Steel, 1.09 for Bethlehem, 1.06 for Republic, 1.07 for National, 1.07 for Jones & Laughlin, 1.05 for Armco, 1.08 for Youngstown, and 1.06 for Inland. To make clear the nature of the possible biases, IV:15a is recast as follows:

$$MC_i = \alpha \hat{C}_{1i} \beta \hat{TC}_i / q_i \qquad \text{VII:1}$$

where

α = The ratio of true C_{1i} to the measured cost elasticity, $\hat{C}_{1i}$,

β = The ratio of the true TC_i to the measured total cost, $\hat{TC}_i$.

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[1] When the cost curves were measured with the depreciation left in the dependent variable, the cost-output elasticities were not materially different. As shown below, our sensitivity analysis should cover the possibility that leaving the depreciation in the cost was the appropriate method.

The above depreciation ratios are the maximum plausible values for β. They give an indication of how much accounting measurement problems could bias the δ_i estimate. The formula also suggests a way to correct for this problem. To illustrate, use U.S. Steel as an example, and assume α equals one (with C_{1i} equalling 0.695). The depreciation ratio, 1.07, is the maximum β. Then, if $\beta T\hat{C}_i$ were the true total cost and if C_{1i} were represented to be $\beta\hat{C}_{1i}$ which equals 0.744, then, an accurate measurement of the c.v. would be made. It is not possible to know the real β, but the above ratios give an indication of its range. Consequently, varying the value of C_{1i} may not only be a way to see how the results change for different cost elasticities but also a test of the sensitivity of the c.v. value to measurement error in TC_i.

Therefore, to see how measurement errors could affect the results, the conjectural variations were estimated for three alternatives C_{1i}'s. The largest cost elasticity we hypothesized, 1.2, assumes that the steel firms were operating in a region of increasing costs under almost any conceivable accounting cost measurement error. Many of the c.v.'s are less than -1, some significantly so statistically.[1] Such a c.v. implies that the firm is operating at a point where price is less than marginal cost. These results not only occurred during the depression when such events might be expected but also in the 1920's and 1960's

[1] With the alternative simulations, it will be assumed that the C_{1i} has the variance measured by our cost model.

when the steel industry was quite prosperous. Therefore, since these results seem implausible, this particular simulation will be ignored.

Two other alternative C_{1i}'s seem more plausible; the first is

C_{1i} = measured C_{1i} + 2 * SD($\hat{C}_{1i}$), the measured standard deviation.

For the second, the output-cost elasticity equals one. The simulation under the latter assumption not only shows what the c.v.'s might be under constant returns but also gives an indication of what they might be if there were slightly increasing cost curves.

When the tests were made with the different C_{1i}'s predictably the results were mixed, but certain conclusions could be made. (For a synopsis see the tables in the Appendix.) First, with the two variations, at no time could the Patinkin hypothesis be accepted. Second usually the competitive hypothesis could be rejected. For the average c.v., the t test led to the rejection of the competitive hypothesis for all firms in both variations except for Republic under the unity C_{1i} assumption.

For the matching and Cournot hypotheses, on the other hand, the results were sensitive to changes in C_{1i}. For U.S. Steel, assuming C_{1i} equal to one implies that the average c.v. was significantly below zero. With the yearly results the Cournot hypothesis could be accepted for only six years.

With Bethlehem and Republic, the results from the two variations mean that matching behavior could be rejected for the average c.v. and the bulk of the yearly observations. On the other hand, the acceptance of matching behavior for the smaller firms was insensitive to the variation of C_{1i} by two standard deviations. But assuming a unity C_{1i} led to the rejection of the matching hypothesis for the average c.v. for National, Jones & Laughlin, Armco, and Youngstown but not for Inland. For these five firms and Republic, the yearly results were generally mixed for the matching hypothesis. Consequently for this hypothesis the results can be sensitive to changes in the nature of the cost structure estimates.

To sum up, pure competition and perfect collusion could be rejected for all firms in most years under all three plausible cost structure estimates. For U.S. Steel matching behavior can be rejected for all years under all cost assumptions. With the other firms, however, matching behavior may sometimes not be rejected for the two alternative C_{1i} assumptions. If the "Big Eight" firm cost curves were flat or slightly upsloping, then, these firms operated in a conjectural variation range near the Cournot or zero point. Nevertheless, if one believes the downsloping curves as measured by this and other papers by the author, then, matching behavior may be accepted for the smaller five firms if not always for Bethlehem and Republic. On the other hand, U.S. Steel seems to have operated in a range that was close to Cournot and perhaps even adaptive.

VIII. Conclusion

The tests for competitive, Cournot, matching, and Patinkin behavior show that different firms apparently behaved differently. Except perhaps for Bethlehem and Republic, most firm c.v.'s were fairly consistent over time. These two firms generally alternated between c.v.'s consistent with the Cournot theory and those consistent with matching behavior. With the measured C_{1i} simulations, the c.v.'s of Jones & Laughlin, Armco, Youngstown, and Inland were almost always consistent with the matching hypothesis, but for the unity C_{1i} simulation such behavior can only be generally accepted for Inland.

The fact that the largest firm acted like a Cournot player, while smaller firms acted in a matching fashion, seems strange. Possibly fear of the antitrust authorities may have constrained U.S. Steel but not the others. Also it may be that U.S. Steel was acting in a manner that cannot be clarified from merely studying its c.v.'s, and perhaps some hypotheses on interfirm relationships should be examined. Furthermore, the cost structure of U.S. Steel may have prevented more restrictive behavior. At low capacity utilization rates, a high cost firm can not hold back output as much as other companies. There is some evidence that this firm was not particularly efficient and might even have been a high cost producer (see Weiss, 1971). The specific inter-firm relationships that led this situation may be the subject for another paper.

To summarize, with our methodology it was found that during the sample period the major American steel firms conformed to two basic behavior patterns; one was close to Cournot but significantly different from competitive. It was followed by U.S. Steel and at least sometimes by Bethlehem and Republic. A second pattern generally followed by the other five "Big Eight" firms, was usually consistent with matching behavior. These results were not particularly sensitive to small variations in the estimated cost parameters. But they did change somewhat when the average cost curves were assumed to be flat.

Consequently, this methodology can be used to study and analyze the position of various oligopoly firms on the continuum between competitive behavior and Patinkin collusion. Nevertheless, while one may be able to place a firm at a point in this range, the methodology can not shed light on how it got there. Still this analysis can show how well or poorly given firms and industries perform; thereby perhaps indicating where antitrust resources should be focused.

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Table A-I

The Average Conjectural Variations for the "Big Eight" Steel Companies for 1920-40 and 1946-72, and t-Test Values for the Hypotheses that the Calculated Values Differed from the Expected Values for Competitive, Cournot, and Patinkin Behavior Under the Assumption that C_1 equals the Measured Value Plus Two Times the Standard Deviation

			t-Values for		
Firm	Average Conjectural Variation	Standard Deviation	Competitive Behavior	Cournot Behavior	Patinkin Collusion
U.S. Steel	-0.134	0.250	3.46*	-0.54	-6.13*
Bethlehem	0.682	0.605	2.78*	1.13	-6.73*
Republic	1.419	1.359	1.78*	1.04	-8.78*
National	2.812	1.592	2.39*	1.77*	-6.79*
Jones & Laughlin[1]	4.674	1.622	3.50*	2.88*	-5.42*
Armco	6.787	3.504	2.22*	1.94*	-5.01*
Youngstown[1]	4.330	1.579	3.38*	2.74*+	-8.09*
Inland	2.985	1.387	2.87*	2.15*+	-11.06*

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

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

1 Now part of the LTV Corporation.

Table A-II

The Average Conjectural Variations for the "Big Eight" Steel Companies for 1920-40 and 1946-72, and t-Test Values for the Hypotheses that the Calculated Values Differed from the Values Expected for Competitive, Cournot, and Patinkin Behavior Under the Assumption That C_1 Equals 1.0

			t-Values for		
Firm	Average Conjectural Variation	Standard Deviation	Competitive Behavior	Cournot Behavior	Patinkin Collusion
U.S. Steel	-0.617	0.135	2.84*	-4.57+	-14.93*
Bethlehem	0.028	0.475	2.16*	0.06	-9.95*
Republic	0.869	1.283	1.46	0.68	-9.73*
National	1.724	1.425	1.91*	1.21	-8.35*
Jones & Laughlin[1]	0.964	0.823	2.39*	1.17	-15.19*
Armco	2.442	2.820	1.22	0.87	-7.77*
Youngstown[1]	1.699	1.022	2.64*	1.66	-15.07*
Inland	2.544	1.298	2.73*	1.96*	-12.16*

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

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

1 Now part of the LTV Corporation.

Table A-III

The Number of Years for Which the Conjectural Variations are Consistent with Various Behavior Hypotheses Under the Assumption that C_1 equals the Measured C_1 Plus Two Times the Measured Standard Deviation

	The Number of Years When the Conjectural Variation was Consistent with[1]			
Firms[2]	Competitive Behavior	Cournot Behavior	Matching Behavior	Patinkin Collusion
U.S. Steel	0(48)	36(12)	0(48)	0(48)
Bethlehem	0(48)	45(3)	5(43)	0(48)
Republic	5(43)	41(7)	8(40)	0(48)
National	0(33)	27(6)	21(12)	0(33)
Jones & Laughlin[3]	0(45)	0(45)	45(0)	0(45)
Armco	1(47)	7(41)	47(1)	0(48)
Youngstown[3]	0(47)	0(47)	47(0)	0(47)
Inland	0(48)	9(39)	41(7)	0(48)

[1] The conjectural variation is considered consistent with given behavior if its value is not significantly different from the postulated value at the 5-percent level.

[2] The number of years when the behavior is not considered consistent with the named behavior is in parentheses.

[3] Now part of LTV Corporation.

Table A-IV

The Number of Years for Which the Conjectural Variations are Consistent with Various Behavior Hypotheses Assuming C_1 Equals 1.

	The Number of Years When the Conjectural Variation was Consistent with[1]			
Firms[2]	Competitive Behavior	Cournot Behavior	Matching Behavior	Patinkin Collusion
U.S. Steel	2(46)	6(42)	0(48)	0(48)
Bethlehem	4(44)	48(0)	0(48)	0(48)
Republic	10(37)[4]	41(7)	6(42)	0(48)
National	7(26)	33(0)	3(30)	0(33)
Jones & Laughlin[3]	6(39)	40(5)	15(30)	0(45)
Armco	14(34)	44(4)	14(34)	0(48)
Youngstown[3]	3(44)	29(18)	35(12)	0(47)
Inland	2(46)	28(20)	41(7)	0(48)

1 The conjectural variation is considered consistent with given behavior if its value is not significantly different from the postulated value at the 5-percent level.

2 The number of years when the behavior is not considered consistent with the named behavior is in parentheses.

3 Now part of LTV Corporation.

4 One observation was significantly less than -1.