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Ernst R. Berndt, Ann F. Friedlaender, and Judy Shaw-Er Wang Chiang*

*Professor of Applied Economics, MIT Sloan School of Management; Professor of Economics, MIT Department of Economics; and Visiting Economist, MIT Center for Energy Policy Research. Research support from the National Science Foundation and from the MIT Center for Energy Policy Research is gratefully acknowledged, as is the research assistance of Mark Showalter, Hua He, Christopher Vellturo and Deborah Nungester.

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ABSTRACT

Our purpose in this paper is to develop and estimate a model of the US automobile industry that can be used to analyze the secular and cyclical strategic markup behavior and market structure of its three major domestic producers -- GM, Ford and Chrysler. The principal novelty in this paper is not such much in the underlying theory (we build on what Timothy Bresnahan has called the "new empirical industrial organization" literature), but rather in the actual empirical implementation of a multi-equation model sufficiently general to permit the testing of a variety of specific behavioral postulates associated with the interdependent strategic profit-maximizing behavior of GM, Ford and Chrysler.

Using firm-specific annual data from 1959-83, we find that at usual levels of statistical significance, we cannot reject Cournot quantity-setting behavior, nor can we reject leader/follower quantity-setting behavior with GM as leader and Ford and Chrysler as followers; the parameter restrictions associated with leader/follower behavior are slightly more binding than those with Cournot, although the difference is not decisive. In terms of the cyclical analysis of market behavior, our most striking result is the great diversity of behavior we find among GM, Ford and Chrysler. Depending on which firm is being analyzed, there is support for the pro-cyclical "conventional wisdom" of markups (GM and Ford), as well as for the counter-cyclical "revisionist" literature (Chrysler). Diversity, rather than constancy and homogeneity, best characterizes firms in this industry.

Address Correspondence to: Prof. Ernst R. Berndt
MIT Energy Laboratory, E40-431
1 Amherst St.
Cambridge, MA 02139
(617)-253-6345

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I. INTRODUCTION

In recent years a considerable literature has emerged reporting results from estimating the market structure of a number of industries, and the behavioral relations among firms within these industries. Much of this literature is based on a theoretical framework recently surveyed by Timothy Bresnahan [1989]. Bresnahan outlines an econometric approach to measuring market power, in which parametric representations rather than accounting data are employed to measure unobservable marginal cost and markups; he calls this the "new empirical industrial organization" (NEIO). Data limitations, however, have made it difficult to develop models that can be used to test explicit behavioral hypotheses concering firms' interdependent pricing and markup behavior.[1] Thus most of the analyses to date have tended to focus on the exercise of market power by broad industry aggregates (e.g., Gollop and Roberts [1979], Appelbaum [1982], Hall [1986,1988], Domowitz, Hubbard and Peterson [1988], Morrison [1988,1990]), or by product type (Bresnahan [1981]).

This suggests that it would be fruitful to employ the basic theoretical framework of the NEIO, but to implement it empirically on several individual firms in one industry for which firm-specific micro-economic data can be constructed. In this connection the auto industry appears to be particularly promising for a number of reasons.[2]

First, during the past two decades, this industry has been subject to significant exogenous shocks (e.g., the dramatic oil price changes and the apparent shift in consumer tastes toward Japanese cars), and thus it is of interest to analyze changes in firm and industry behavior in response to such shocks. Second, since the automobile industry has often been characterized as a "classic oligopoly", it is particularly attractive for assessing the relevance of models of oligopolistic behavior, such as Courtnot quantity-setting and leader/follower models. Third, Friedlaender, Winston and Wang [1983] and Aizcorbe, Winston and Friedlaender [1987] have constructed a data set on the auto industry, thereby permitting a much richer characterization of firm and industry costs and market behavior than has generally been available in empirical models of this nature.

Our purpose in this paper, therefore, is to develop and estimate a model of the US automobile industry that can be used to analyze the secular and cyclical strategic behavior and market structure of its major domestic producers -- GM, Ford and Chrysler. The principal novelty in this paper is not so much in the basic methodology (we build on the NEIO), but rather in the empirical implementation of a multi-equation model sufficiently general to permit the testing of a variety of specific behavioral postulates associated with the strategic profit maximizing behavior of firms in the US auto industry. We also analyze the nature and cylicality of the firm-specific exercise of market power.

Our paper takes the following form. In Section II we outline a theoretical framework that can be used to test various behavioral hypotheses (unconstrained profit maximization, Cournot quantity-setting behavior, and leader/follower conduct). In Section III we discuss issues involved in empirical implementation, overview the data and detail the stochastic specification, and then in Section IV we present and interpret a host of empiririical results. Finally, in Section VI we summarize and suggest issues for future research. Three appendices accompany this paper, the first concerning data construction and sources, the second presenting a stylized framework for understanding cyclical variations in markups, and the third consisting of tables with additional econometric results.

II. THEORETICAL FRAMEWORK

In this section we first describe a simple Cournot model of myopic behavior in which each firm assumes others will not respond to its profit-maximizing quantity-setting behavior. We develop specific hypothesis tests to assess whether this strategic behavioral assumption can be accepted or rejected. We then develop a leader/follower model that also involves testable cross-equation parameter restrictions. A priori, we do not expect that either of these extreme cases adequately describe the complexities of oligopolistic markets, and therefore we indicate how our framework can be generalized to analyze the exercise of market power among firms and over time, without relying on such restrictive and specific behavioral hypotheses concerning firm interactions. It is worth emphasizing, however, that the constraints imposed by empirical implementability compel us to work within an essentially static optimization context. Since in fact the process of strategic interaction among firms is inherently dynamic, at best our static models should be viewed as reduced form solutions to these dynamic games or interactions.[3]

We begin by assuming there are three firms whose products are close substitutes, and that each firm sets quantities so as to maximize expected profits.[4] For simplicity, we assume each firm produces a single product, although this is not essential to the argument. Let y_i be the production level of each firm, whose costs depend on its output level alone (for notational simplicity we suppress the other arguments of the cost function),

$$C_i = C_i(y_i). \tag{1}$$

However, the demand and therefore the revenue functions of each firm depend not only upon its own output, but also on the output of the other firms. We can thus characterize the revenue function of each firm as

$$R_i = R_i(y_1,y_2,y_3), \quad i = 1,2,3 \tag{2}$$

and each firm's profit function as

$$\pi_i(y_1,y_2,y_3) = R_i(y_1,y_2,y_3) - C_i(y_i), \quad i = 1,2,3. \tag{3}$$

Thus far, our analysis is entirely general and incorporates no specific behavioral assumptions. It should be clear, however, that the key elements are the revenue functions and the extent to which each firm recognizes demand interdependencies embodied in (2) and exploits them in maximizing profits in (3). We begin by analyzing the simplest case of myopic firm behavior, in which each firm follows the Cournot assumption that its quantity-setting behavior will not lead to quantity responses on the part of its competitors, resulting in the familiar Nash equilibrium. In this case, each firm maximizes its profits using the usual marginal revenue/marginal cost (MR/MC) conditions

$$\frac{\partial R_i(y_i,\bar{y}_j,\bar{y}_k)}{\partial y_i} = \frac{\partial C_i(y_i)}{\partial y_i}, \quad i = 1,2,3 \text{ and } i \neq j,k, \tag{4}$$

where the superscript bars indicate that the firm views the output of its competitors as being exogenous and thus not influenced by its behavior. As Bresnahan [1989] has shown, if one specifies revenue as the product of the inverse demand function and output quantity, equation (4) can be re-written as the following profit-maximizing behavioral expression for each firm:

$$P_i = MC_i - \frac{\partial P_i(y_i,\bar{y}_j,\bar{y}_k)}{\partial y_i} \cdot y_i \tag{5}$$

As another extreme example, consider a leader/follower model in which firm 1 acts as a leader and the other two firms act as followers. Assume that firm 1 recognizes the interdependency of demand and therefore determines its profit maximizing quantity level taking this interdependence into account. Firms 2 and 3 then observe this output and determine their profit maximizing output simultaneously, ignoring any interdependency between their own demand and that of their competitors. It is worth noting that although this process is inherently dynamic and sequential, for empirical purposes we model it as being simultaneous and static. Since the period of observation is typically a year, this appears to be a plausible assumption, for the automobile product or reaction cycle is generally less than a year.[5]

If firms 2 and 3 act as Cournot followers, their revenue function is given by

$$R_i = R_i(\bar{y}_1, y_i, \bar{y}_j), \quad i = 2,3 \text{ and } i \neq 1,j \tag{6}$$

where the superscript bars indicate that other firms' outputs are viewed as being exogenous from the perspective of firm i. Thus each follower will maximize its profits using the traditional MR/MC condition

$$\frac{\partial R_i(\bar{y}_1, y_i, \bar{y}_j)}{\partial y_i} = \frac{\partial C_i(y_i)}{\partial y_i}, \quad (i,j) = (2,3), (3,2), \tag{7}$$

which yields a reaction function for each follower as

$$y_i = \phi_i(y_1, \bar{y}_j), \quad i = 2,3 \text{ and } i \neq j. \tag{8}$$

However, since y_j is also a function of y_1 and y_i, (8) can also be written as

$$y_i = \phi_i(y_1, \phi_j(y_1, y_i)) \tag{9}$$

which can be solved for y_i as a function of y_1 alone:

$$y_i = y_i(y_1), \quad i = 2,3. \tag{10}$$

Now if firm 1 correctly perceives the behavioral response of firms 2 and 3, it can utilize this information in its revenue function, now written as

$$R_1 = R_1(y_1, y_2(y_1), y_3(y_1)). \tag{11}$$

Using the chain rule, we derive the MR/MC condition for firm 1 as

$$\frac{\partial R_1}{\partial y_1} = \frac{\partial R_1}{\partial y_1} + \frac{\partial R_1}{\partial y_2} \cdot \frac{\partial y_2}{\partial y_1} + \frac{\partial R_1}{\partial y_3} \cdot \frac{\partial y_3}{\partial y_1} = \frac{\partial C_1}{\partial y_1}. \tag{12}$$

Alternatively, since $R_1 = y_1 \cdot P_1[y_1, y_2(y_1), y_3(y_1)]$, the MR/MC condition can also be written as

$$P_1 = MC_1 - y_1 \cdot \frac{\partial P_1[y_1, y_2(y_1), y_3(y_1)]}{\partial y_1} \tag{13}$$

where $\partial P_1/\partial y_1$ is the derivative of firm 1's inverse demand function with respect to its own output, taking a form analogous to the derivative of revenue with respect to y_1 in equation (12).

It is of course the case that the behavior of firms in oligopolistic markets is extremely complex, and thus it would not be surprising if firms behaved in ways more complicated than that implied by the relatively simple Cournot or leader/follower models.[6] It is useful, therefore, that we recognize this complexity explicitly and rewrite the MR/MC condition, more generally than in (5) or (13), as

$$P_i = MC_i - \frac{\partial P_i(\cdot)}{\partial y_i} \cdot y_i \tag{14}$$

where the expression $\partial P_i(\cdot)/\partial y_i$ is an unspecified relationship among interdependent firms' prices and outputs.

It should be noted that the general form of the MR/MC conditions in the case of competitive (Cournot) oligopolistic behavior, the leader/follower behavior, and the generalized maximizing behavior is identical, with the difference being in the nature of the term reflecting the response of the own price of a given firm to changes in its own output, $\partial P_i/\partial y_i$. Hence, in terms of econometric implementation, while the general specification of each of these cases is identical, the precise interpretation of the coefficients embedded in $\partial P_i/\partial y_i$ will differ under alternative behavioral assumptions.

III. TOWARDS AN EMPIRICAL SPECIFICATION

To implement this rather general theoretical framework empirically, functional forms must be specified for the cost and output demand functions, and stochastic assumptions must be detailed. We assume the cost function for the i^{th} firm can be approximated using the normalized quadratic form[7]

$$\tilde{C}_i = \alpha_{0i} + \sum_{s=1}^{n-1} \alpha_{is}\tilde{w}_{is} + .5\cdot \sum_{s=1}^{n-1} \sum_{k=1}^{n-1} \alpha_{isk}\tilde{w}_{is}\tilde{w}_{ik} + \sum_{s=1}^{n-1} \alpha_{isy}\tilde{w}_{is}y_i + \sum_{s=1}^{n-1} \alpha_{ist}\tilde{w}_{is}t_i$$

$$+ \alpha_{iy}y_i + .5\cdot\alpha_{iyy}y_i^2 + \alpha_{it}t_i + \alpha_{ity}t_iy_i + .5\cdot\alpha_{itt}t^2 \qquad (15)$$

where w_{in} is the unnormalized price of the n^{th} input for firm i, $\tilde{w}_{is} = w_{is}/w_{in}$ is the normalized input price, unnormalized costs are C_i, normalized costs are $\tilde{C}_i = C_i/w_{in}$, and t_i is a product mix variable (defined as the proportion of large vehicles -- greater than 3,000 lbs. -- in total vehicle production). Denoting input quantities for the i^{th} firm as x_{is}, $s = 1,\ldots,n$, it follows that

$$C_i = \sum_{s=1}^{n} w_{is}x_{is} \quad \text{and} \quad \tilde{C}_i = \sum_{s=1}^{n-1} \tilde{w}_{is}x_{is} + x_{in}. \qquad (16)$$

Using Shephard's Lemma, we obtain the cost-minimizing demand functions for n-1 inputs as

$$x_{is} = \frac{\partial \tilde{C}_i}{\partial \tilde{w}_{is}} = \alpha_{is} + \sum_{k=1}^{n-1} \alpha_{isk}\tilde{w}_{ik} + \alpha_{isy}y_i + \alpha_{ist}t_i, \quad s=1,\ldots,n-1, \qquad (17)$$

and derive the cost-minimizing demand for the normalized input x_{in} by solving the second equation in (16) for x_{in} and then substituting (15) for $\tilde{C}_i$ and (17) for x_{is}. We further specify that each firm's inverse demand function can be written as a linear approximation, with each firm's output being imperfectly substitutable. We write this inverse demand function facing each of the three automakers as

$$\tilde{P}_i = \sum_{j=1}^{3} \delta_{ij} y_j + \delta_i' z \tag{18}$$

where $\tilde{P}_i = P_i/w_{in}$ is the normalized output price and z is a vector of exogenous variables common to all three firms. This normalization is needed to ensure consistency between the cost and demand functions, and the MR/MC conditions. Firm-specific revenue functions are therefore given by

$$\tilde{R}_i = y_i \cdot \tilde{P}_i(y_1, y_2, y_3, z) = y_i \cdot \left[\sum_{j=1}^{3} \delta_{ij} y_j + \delta_i' z \right]. \tag{19}$$

Solving for the MR/MC equilibrium condition within this framework yields the following general expression, analogous to (5):

$$\begin{aligned} \tilde{P}_i &= \tilde{MC}_i + \lambda_i y_i \\ &= \alpha_{iy} + \alpha_{iyy} y_i + \sum_{s=1}^{n-1} \alpha_{isy} \tilde{w}_{is} + \alpha_{ity} t_i + \lambda_i y_i \end{aligned} \tag{20}$$

where λ_i takes on different specific values depending on the behavioral model being postulated. We now consider several special cases of λ_i.

Consider first the case of Cournot behavior, where each firm treats the other's output as constant.[8] This yields an expression for λ_i in (20) as

$$\lambda_i = -\delta_{ii}, \quad i = 1,2,3. \tag{21}$$

Thus, to test the Cournot model as a special case of the more general framework in (20), we impose the three coefficient restrictions in (21), in addition to the cross-equation coefficient restrictions required to ensure consistency among the parameters estimated in the input demand functions, the output demand functions, and the MR/MC condition.[9]

An alternative behavioral assumption is that the auto market is characterized by leader-follower relationships. Let firm 1 be the leader, and firms 2 and 3 be Cournot followers. For firms 2 and 3, the MR/MC conditions take the form of equations (20) and (21). For the leader firm, however, the MR/MC condition is more complex, for it must incorporate the reaction functions of firms 2 and 3. These reaction functions are obtained by substituting the right-hand side of the follower's inverse demand function (18) for the left-hand price term in the followers' MR/MC condition (20) and (21), and then solving for each follower's output as a function of the other firms' outputs and the exogenous variables. This yields

$$y_i = \phi_i(y_1, y_k) = \frac{M_i - \delta_i' z - \delta_{i1} y_1 - \delta_{ik} y_k}{2\delta_{ii} - \alpha_{iyy}}, \quad i = 2,3 \text{ and } i \neq k \qquad (22)$$

where M_i, part of the marginal cost term for the follower firms, is defined as

$$M_i = \alpha_{iy} + \sum_{s=1}^{n-1} \alpha_{isy} \bar{w}_{is} + \alpha_{ity} t_i, \quad i = 2,3. \qquad (23)$$

The above expression yields a system of two equations (one for each follower firm) that can be solved in terms of y_1, the exogenous elements in the demand function z, and the elements of the partial marginal cost function M_i, which then generate the leader's revenue function as

$$\tilde{R}_1 = y_1 \cdot \tilde{P}_1[y_1, y_2(y_1, M_2, \delta_2' z), y_3(y_1, M_3, \delta_3' z)] \qquad (24)$$

where $y_i(y_1, M_i, \delta_i' z)$, i = 2,3, can be expressed as

$$y_2 = [(2\delta_{33} - \alpha_{3yy}) \cdot (M_2 - \delta_{21} y_1 - \delta_2' z) - \delta_{23}(M_3 - \delta_{31} y_1 - \delta_3' z)]/\Delta \qquad (25)$$

$$y_3 = [(2\delta_{22} - \alpha_{2yy}) \cdot (M_3 - \delta_{31} y_1 - \delta_3' z) - \delta_{32}(M_2 - \delta_{21} y_1 - \delta_2' z)]/\Delta \qquad (26)$$

and where

$$\Delta = (2\delta_{22} - \alpha_{2yy}) \cdot (2\delta_{33} - \alpha_{3yy}) - \delta_{32}\delta_{23}. \qquad (27)$$

Finally, substituting (25) and (26) into the leader's inverse demand function (18), differentiating it with respect to y_1, and then substituting these derivatives into the leader's MR/MC condition (13) yields a value for λ_1 in (20) that can be written as

$$\lambda_1 = \{ -\delta_{11} + \delta_{12}[\delta_{21}(2\delta_{33} - \alpha_{3yy}) - \delta_{23}\delta_{31}]/\Delta + \delta_{13}[\delta_{31}(2\delta_{22} - \alpha_{2yy}) - \delta_{21}\delta_{32}]/\Delta\} \ . \tag{28}$$

This completes the specification of our leader-follower model. Note that although the leader-follower model has restrictions on the λ_i parameters for firms 2 and 3 that are identical to the Cournot model, the restriction on λ_1 in (28) implied by the leader-follower model is quite different from that for λ_1 in the Cournot model (21). Hence, the Cournot and leader-follower models each involve three independent restrictions on the λ_i parameters, and the models are non-nested.

Furthermore, by estimating equation (20) directly without constraint, the above framework can be used to analyze the degree of market power and how it may have changed over time. Specifically, since $\tilde{P}_i - \tilde{MC}_i = \lambda_i \cdot y_i$, where λ_i is a parameter estimated from the MR/MC condition (20), one can assess the extent to which firms have exercised their market power, without imposing specific strategic behavioral assumptions. By allowing the markup to change over time in response to various supply and demand shocks, one can also determine how the exercise of market power changes with respect to different market conditions, stages of the business cycle, and so forth.[10]

Before proceeding with a discussion of data and stochastic specification, we now briefly consider several other issues in empirical implementation. For each of the three automakers, we specify three inputs whose prices enter the firm-specific cost function: materials (x_M), capital (x_K) and labor (x_L). Since problems in constructing reliable micro-data on capital input are particularly troublesome and well-known, we employ a long-run cost function and treat capital as a variable input, thereby implicitly assuming that the measurement error problems associated with having x_K as a regressor are potentially more significant than the possible mis-specification resulting from treating that input as variable rather than fixed in the short-run.

To ensure that the cost function is homogeneous in factor prices, we normalize costs and input prices by the price of labor, w_L. We jointly estimate the materials, capital and labor input demand equations, where the normalized cost function (15) is substituted into the labor demand equation implicit in (16). Thus our system of cost-input demand equations takes the following form:

$$x_{Mi} = \alpha_{i1} + \alpha_{i11}\tilde{w}_{i1} + \alpha_{i12}\tilde{w}_{i2} + \alpha_{i1y}y_i + \alpha_{i1t}t_i \tag{29}$$

$$x_{Ki} = \alpha_{i2} + \alpha_{i12}\tilde{w}_{i1} + \alpha_{i22}\tilde{w}_{i2} + \alpha_{i2y}y_i + \alpha_{i2t}t_i \tag{30}$$

$$x_{Li} = \alpha_{0i} + \alpha_{iy}y_i + \alpha_{it}t_i + \alpha_{ity}t_iy_i + .5\cdot\alpha_{itt}t_i^2 + .5\cdot\alpha_{iyy}y_i^2 - .5\cdot\alpha_{i11}\tilde{w}_{i1}^2 - \alpha_{i12}\tilde{w}_{i1}\tilde{w}_{i2} - .5\cdot\alpha_{i22}\tilde{w}_{i2}^2 \tag{31}$$

The output demand relationships for each firm are estimated by using a linear approximation to a normalized inverse demand function

$$\tilde{P}_i = \delta_{0i} + \sum_{j=1}^{3}\delta_{ij}y_j + \delta_{4i}GNP + \delta_{5i}INR + \delta_{6i}UN + \delta_{7i}GAS + \delta_{8i}CPI + \delta_{9i}EXR\ , \quad i = 1,2,3, \tag{32}$$

where GNP is real gross national product, INR is the interest rate, UN the unemployment rate, GAS the real gas price, CPI the consumer price index, and EXR the dollar/yen exchange rate, all defined at the bottom of Table 1.

To estimate marginal costs and markups, we specify and then estimate parameters in a system of equations consisting of demand equations for three inputs (capital, labor and materials), an inverse output demand equation, and an equation based on the profit maximization assumption of marginal revenue equals marginal cost, where the marginal revenue equation includes the conjectured strategic response of other firms. This five equation system is specified for each of the three firms, GM, Ford and Chrysler, and the resulting 15-equation system is estimated using the method of nonlinear three-stage least squares (3SLS), with appropriate cross-equation constraints imposed (both within and between firms) to ensure consistency among the equations.

A distinguishing feature of this research effort is that we employ firm-specific data. Although there are numerous well-known problems in constructing reliable micro data, we view our modelling effort with firm-specific data as somewhat exploratory, helping us to assess whether employing data with admitted deficiencies generates plausible findings. In our context, the data requirements for the markup and interdependent pricing model include prices and quantities of output and the three inputs for each firm, a product mix variable for each firm (the proportion of large vehicles in total vehicle production), as well as a set of exogenous demand-shifting variables common among the three firms.

The data set for this study consists of annual data from 1959-83, based on that originally constructed and employed by Ana Aizcorbe, Clifford Winston and Ann F. Friedlaender [1987]. We describe this data set in greater detail (particularly our extensions) in Appendix I to this paper. These data are summarized, however, in Table 1 below, where we present variable definitions as well as sample means, minimum and maximum values, and standard deviations for all the variables used in our empirical analysis.

In terms of endogenous and exogenous variables, we assume that the macro-economic inverse demand equation variables in (32) are exogenous, as are the input price variables; however, output quantity, output price (and implicitly, marginal cost and markup) are endogenous, as are input quantities

TABLE 1

SUMMARY STATISTICS FOR 1959-1983 AUTOMOBILE MANUFACTURING DATA SET

COMPANY	VARIABLE	MEAN	MIN VALUE	MAX VALUE	STD. DEV.
GM	Materials Input	21496.23	12994.46	30716.98	5388.78
	Labor Input	521.18	421.26	618.36	57.41
	Capital Input	163.62	61.88	277.73	59.15
	Materials Price	0.76	0.34	1.08	0.26
	Labor Price	25.71	13.15	33.95	7.35
	Capital Price	54.08	14.29	98.70	30.48
	Output Quantity	4.94	2.97	6.72	1.12
	Output Price	5951.35	4779.30	6589.17	495.00
	Product Mix	0.72	0.35	0.85	0.14
FORD	Materials Input	12525.96	8359.32	20136.33	3369.09
	Labor Input	208.24	148.36	256.61	34.96
	Capital Input	122.12	37.55	223.45	67.77
	Materials Price	0.84	0.42	1.24	0.28
	Labor Price	23.67	11.49	33.73	7.40
	Capital Price	52.30	9.80	113.01	35.55
	Output Quantity	2.55	1.52	3.77	0.61
	Output Price	5968.43	5141.47	6625.85	363.72
	Product Mix	0.57	0.14	0.85	0.21
CHRYSLER	Materials Input	5206.45	2116.06	8064.78	1818.51
	Labor Input	113.85	45.96	178.09	31.16
	Capital Input	48.46	13.97	147.83	34.40
	Materials Price	0.96	0.59	1.21	0.23
	Labor Price	21.16	8.67	28.44	6.80
	Capital Price	50.55	9.33	107.53	33.75
	Output Quantity	1.17	0.54	1.69	0.34
	Output Price	5986.05	5427.33	6937.95	387.52
	Product Mix	0.62	0.03	0.89	0.23
COMMON DEMAND VARIABLES:					
	GNP	1411.60	868.93	1805.46	308.41
	Interest Rate	1.38	-3.50	4.61	2.26
	Unemployment Rate	5.98	3.50	9.70	1.70
	Gasoline Price	221.22	117.95	309.59	68.11
	CPI	1.05	1.00	1.15	0.05
	Exchange Rate	4.19	2.36	5.13	9.45

Definitions and Units of Measurement:

Material Input	Materials Cost/Materials Price Index, $ Millions
Labor Input	Labor Cost/Labor Price Index, $ Millions
Capital Input	Capital Costs/Capital Price Index, $ Millions
Material Price	1975 $ per pound of material

Labor Price	Thousand $ per worker per year
Capital Price	Rental price, percentage points
Output Quantity	Millions of autos produced
Output Price	Average Revenue ($ per auto)
Product Mix	Share of Intermediate Size Autos Produced
GNP	Gross National Product in $1982 Billions
Interest Rate	U.S. Treasury bond yield minus percent change in GNP deflator
Unemployment	Unemployment Rate, Percentage Points
Gasoline Price	Gasoline Price Index/CPI, 1967 = 100
CPI	Consumer Price Index, 1975 = 1.00
Exchange Rate	US Dollars/1,000 Japanese Yen

Note: In estimation, all prices and dollar-denominated exogenous demand variables are deflated by the GNP deflator; all are in $1975.

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demanded. Although we do not explicitly model determinants of the product mix variable, in estimation we treat it as jointly determined and account for possible simultaneity by employing an instrumental variable estimator. Each of our equations is over-identified. We append an additive disturbance term to each of the fifteen equations in our system, and assume that the resulting disturbance vector is identically and independently multivariate normally distributed, with mean vector zero and nonsingular disturbance covariance matrix Ω. Estimation was undertaken using the three-stage least squares commands in the TSP computer software program on a MicroVAX 3200 computer.[11]

As discussed in the previous section, our framework enables us to test the Cournot and leader/follower models as special cases of the most general model in which no constraints are placed on the λ_i parameters. For testing such hypotheses, we employ the Wald (quasi-likelihood ratio) test statistic procedure, as adapted to the nonlinear three-stage least squares context by Gallant and Jorgenson [1979].

IV. EMPIRICAL RESULTS

We now move on to a discussion of empirical findings, first focusing on the type of interdependent pricing behavior we find among GM, Ford and

Chrysler, and then examining more closely the factors affecting the changing markup behavior of these automakers.

In Table 2 we present 3SLS parameter estimates assuming that the three automakers maximize profits, but without specifying the precise nature of their strategic interdependence; as was noted in Section III, under this profit maximization with unconstrained strategic behavior specification, no constraints are placed on the λ_i parameters. In this model, estimates of the cost function parameters α_{11} are negative for all three firms, for α_{22} they are negative for GM and Ford, and for all firms α_{1y} and α_{2y} are positive, as is required by the underlying economic theory of cost and production; the positive estimate of α_{22} for Chrysler is statistically insignificant. Further, as expected, estimates of λ are positive for all three firms; the estimate for GM (4.429) is smallest, while that for Chrysler (92.675) is largest; since from (14) and (20) it is clear that the λ_i are simply interpreted as estimates of $-\partial P_i/\partial Y_i$, the relative values of the λ_i estimates merely suggest that this derivative is smallest for GM and largest for Chrysler. On the output demand side, estimates of the δ_{ii} parameters in the inverse demand equations are all negative, consistent with the theory; while Ford and GM are "substitutes" (estimates of δ_{GF} and δ_{FG} are positive), Chrysler and Ford, and Chrysler and GM are "complements" (estimates of δ_{CF}, δ_{FC}, δ_{CG} and δ_{GC} are negative). Note that in interpreting these parameter estimates, one must recognize their very partial nature; for example, the negative estimate of δ_{GG} implies that if GM increases sales while the quantity of autos sold by Ford and Chrylser is unchanged, then the price of GM cars will fall, <u>ceteris paribus</u>. Estimates of demand elasticities allowing for strategic interactions (both quantity and price) require a different and more

Table 2

3SLS PARAMETER ESTIMATES -- PROFIT MAXIMIZATION
WITH UNCONSTRAINED STRATEGIC BEHAVIOR
(Asymptotic t-statistics in Parentheses)

Parameter	Variable	GM	Ford	Chrysler
α_0	Constant	-972.801 (-5.173)	-797.063 (-9.710)	-307.679 (-11.099)
α_1	w_1	-6523.165 (-2.101)	5220.880 (3.223)	241.192 (0.658)
α_{11}	w_1w_1	-80466.560 (-1.814)	-137283.000 (-3.974)	-12309.290 (-3.185)
α_{12}	w_1w_2	248.978 (0.476)	-709.159 (-3.946)	-358.791 (-7.133)
α_{1y}	w_1y	3864.986 (10.092)	3842.160 (17.120)	3824.265 (25.630)
α_{1t}	w_1t	14919.090 (4.470)	6530.890 (8.187)	2986.129 (9.213)
α_2	w_2	74.572 (1.539)	213.177 (7.449)	121.788 (7.482)
α_{22}	w_2w_2	-9.046 (-1.009)	-16.046 (-4.323)	1.034 (0.560)
α_{2y}	w_2y	21.957 (4.028)	9.942 (1.562)	-32.052 (-6.073)
α_{2t}	w_2t	-11.860 (-0.203)	-105.268 (-3.044)	-34.725 (-1.497)
α_y	y	372.419 (7.642)	388.735 (8.938)	342.829 (13.444)
α_t	t	789.641 (1.706)	1399.696 (6.488)	429.587 (6.364)
α_{ty}	$t \cdot y$	-402.352 (-7.931)	-330.842 (-9.093)	-162.938 (-6.068)
α_{yy}	y^2	-1.842 (-0.215)	-49.287 (-2.756)	-121.366 (-4.913)

α_{tt}	t^2	1825.000	-1763.041	-382.194
		(2.137)	(-4.929)	(-3.097)
λ		4.429	20.044	92.675
		(1.148)	(2.312)	(6.114)
δ_0	Constant	624.744	1045.436	1550.709
		(6.998)	(9.660)	(8.781)
δ_G	y_{GM}	-4.359	12.422	-27.646
		(-0.913)	(2.273)	(-3.068)
δ_F	y_{Ford}	7.677	-48.297	-19.863
		(0.863)	(-4.265)	(-1.082)
δ_C	$y_{Chrysler}$	-34.903	-54.059	-114.771
		(-1.790)	(-2.218)	(-2.859)
δ_4	GNP	-0.289	-0.136	-0.148
		(-7.653)	(-2.918)	(-1.942)
δ_5	Interest Rate	9.633	4.409	11.406
		(5.779)	(2.209)	(3.450)
δ_6	Unemployment	-19.986	-16.543	-27.673
		(-8.781)	(-5.665)	(-5.852)
δ_7	Gas Price	-0.298	-0.932	-2.020
		(-1.990)	(-5.140)	(-6.764)
δ_8	CPI	389.428	40.060	75.229
		(4.114)	(0.340)	(0.392)
δ_9	Exchange Rate	-0.004	-0.004	-0.004
		(-5.946)	(-5.816)	(-3.346)
OTHER STATISTICS				
R^2	Materials	0.777	0.719	0.968
	Capital	0.693	0.729	0.022
	Labor	0.325	0.315	0.647
	Inverse Demand	0.949	0.990	0.975
	MR-MC	0.670	0.733	0.896

System E'HH'E = 320.463   Number of Observations Per Equation = 25

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complex computation than simply examining magnitudes of the δ_{ij} parameters; we discuss such "general equilibrium" demand elasticities later in this section. For the moment, however, note also that signs of the other estimated δ parameters are the same across firms, although the variation in magnitudes is substantial.

At the bottom of Table 2, equation-specific R^2 values are reported; these values appear reasonable (those for the inverse demand equation are particularly gratifying), although the R^2 value for the capital demand equation for Chrysler (.022) is very low.

As we noted in Section III, the Cournot model of strategic interactions is a special case of our most general model, and involves placing three restrictions on the λ_i parameters ($\lambda_i = -\delta_{ii}$, i = GM, Ford and Chrysler). From Table 2 it is clear that the unconstrained estimates of λ_i, particularly for GM and Chrysler, are very close to estimates of $-\delta_{ii}$, and thus it would not be surprising if these restrictions were consistent with our data. In Table 3 we report results from testing Cournot as a special case of the unconstrained profit maximization model; the Wald (quasi-likelihood ratio) test statistic is 3.975, while the chi-square critical values with three degrees of freedom are 4.108 (75% confidence level), 6.251 (90%), and 7.815 (95%). We conclude that the constraints implied by the Cournot model are consistent with our data, given usual confidence levels.

Table 3

RESULTS OF TESTING FOR STRATEGIC BEHAVIOR
USING QUASI-LIKELIHOOD RATIO TEST

H_0: Unconstrained Strategic Behavior H_1: Cournot Behavior	χ^2(3 d.f.) Test Statistic: 3.975
H_0: Unconstrained Strategic Behavior H_1: GM Leader-Follower Behavior	χ^2(3 d.f.) Test Statistic: 4.614

χ^2(3 d.f.) Critical Values: 2.366 (50%), 4.108 (75%), 6.251 (90%), 7.815 (95%)

3SLS parameter estimates with the Cournot strategic behavior restrictions imposed are given in Table 4. A comparison of estimates in Tables 2 and 4 is consistent with implications of the fact that the Cournot restrictions were not rejected, for signs and even magnitudes of the estimated parameters are very similar in the two models, as are the equation-specific R^2 values.

A different special case of our most general model is that implied by leader-follower behavior, with GM acting as leader and Ford and Chrysler as followers; the three restrictions implied by this model are given in (21) for λ_2 and λ_3, and in (28) for λ_1. As is reported in Table 3, the Wald (quasi-likelihood ratio) test statistic for these restrictions is 4.614, while the chi-square critical values are again equal to 4.108 (75% confidence level), 6.251 (90%) and 7.815 (95%). We interpret this finding as suggesting that the restrictions implied by strategic leader-follower behavior are also consistent with our data, but are very slightly more binding than those implied by Cournot behavior; however, the leader/follower restrictions are not sufficiently tight to warrant outright rejection at 90 or 95% levels of confidence. In interpreting these test results, recall from our theoretical discussion that the λ_i restrictions appear directly in the MR/MC equation for each firm, and as seen at the bottom of Table 2, the R^2 values in this equation are all above 0.65, implying that our failure to reject the null hypothesis decisively does not appear to be due to a simple lack of explanatory power under the alternative hypothesis.[12] All we can say is that there is very slightly more support for the Cournot than for the leader-follower model, although the differential is not decisive. To conserve on space, therefore, we do not report 3SLS parameters for the estimated leader-follower model.[13]

Table 4

3SLS PARAMETER ESTIMATES -- PROFIT MAXIMIZATION
WITH COURNOT STRATEGIC BEHAVIOR
(Asymptotic t-statistics in Parentheses)

Parameter	Variable	GM	Ford	Chrysler
α_0	Constant	-1010.470	-819.943	-305.551
		(-5.508)	(-10.092)	(-11.045)
α_1	w_1	-5842.790	5384.825	217.129
		(-1.914)	(3.334)	(0.594)
α_{11}	w_1w_1	-85567.190	-138000.600	-11995.660
		(-1.939)	(-3.999)	(-3.110)
α_{12}	w_1w_2	251.750	-719.311	-352.769
		(0.482)	(-4.010)	(-7.031)
α_{1y}	w_1y	3796.541	3818.231	3800.762
		(10.098)	(17.041)	(25.567)
α_{1t}	w_1t	14712.530	6488.521	3020.875
		(4.414)	(8.139)	(9.339)
α_2	w_2	83.418	230.426	125.754
		(1.734)	(8.457)	(7.812)
α_{22}	w_2w_2	-8.479	-15.280	1.044
		(-0.948)	(-4.174)	(0.567)
α_{2y}	w_2y	21.059	5.434	-33.750
		(3.914)	(0.917)	(-6.616)
α_{2t}	w_2t	-19.908	-114.986	-37.189
		(-0.342)	(-3.362)	(-1.609)
α_y	y	392.435	414.929	348.996
		(8.312)	(10.038)	(13.903)
α_t	t	756.136	1447.706	422.822
		(1.658)	(6.761)	(6.280)
α_{ty}	$t \cdot y$	-410.919	-329.382	-162.461
		(-8.149)	(-9.059)	(-6.065)
α_{yy}	y^2	-5.611	-65.098	-129.612
		(-0.692)	(-4.087)	(-5.391)

α_{tt}	t^2	1970.656	-1859.728	-370.525
		(2.351)	(-5.261)	(-3.016)
λ	Constrained	6.621	30.790	101.348
		(1.996)	(4.675)	(7.315)
δ_0	Constant	619.583	1001.396	1529.041
		(6.955)	(9.462)	(8.826)
δ_G	y_{GM}	-6.621	9.092	-29.712
		(-1.996)	(1.753)	(-3.386)
δ_F	y_{Ford}	9.757	-30.790	-19.613
		(1.174)	(-4.675)	(-1.284)
δ_C	$y_{Chrysler}$	-31.440	-73.631	-101.348
		(-1.679)	(-3.359)	(-7.315)
δ_4	GNP	-0.293	-0.134	-0.168
		(-7.918)	(-2.875)	(-2.753)
δ_5	Interest Rate	9.559	4.356	10.742
		(5.799)	(2.183)	(3.748)
δ_6	Unemployment	-20.034	-16.721	-27.916
		(-9.184)	(-5.729)	(-5.942)
δ_7	Gas Price	-0.296	-0.886	-1.962
		(-2.026)	(-4.929)	(-7.020)
δ_8	CPI	398.845	78.279	103.025
		(4.323)	(0.674)	(0.557)
δ_9	Exchange Rate	-0.004	-0.005	-0.004
		(-5.909)	(-6.413)	(-3.411)
OTHER STATISTICS				
R^2	Materials	0.778	0.723	0.968
	Capital	0.682	0.694	0.023
	Labor	0.290	0.275	0.642
	Inverse Demand	0.950	0.990	0.975
	MR=MC	0.679	0.755	0.901

System E'HH'E = 324.438 Number of Observations Per Equation = 25

We now turn to a discussion of firm-specific estimated returns to scale. With our normalized quadratic cost function (15), not only are cost function parameters and estimated returns to scale firm-specific, but they also vary by observation; our findings suggest that allowing for such diversity among firms and over time is important. In Table 5 we report estimated returns to scale (and estimated standard errors) for five years -- 1959, 1974, 1978, 1980 and 1983, based on the unconstrained, Cournot, and leader/follower behavioral assumptions.

The first striking result here is that for any year, estimates of firm-specific returns to scale are remarkably similar across the three models; this reflects in part the fact that constraints implied by the Cournot and leader/follower models are reasonably consistent with out data. Second, the estimated returns to scale are smallest for GM and largest for Chrysler, a result that is not unexpected given the relative sizes of these firms. Third, although increasing returns to scale are present for all three firms for most of the sample, at the very end of the sample in 1983 scale economies changed to decreasing returns, reflecting perhaps the effects of concerted efforts on the part of automakers to downsize their manufacturing operations and a somewhat stronger demand in 1983 relative to the 1981-82 recessionary years.[14] Finally, note that these returns to scale calculations hold constant the size composition of output, and in that sense correspond to ray elasticities. Elasticities of cost with respect to product mix, as well as other elasticity estimates based on our estimated unconstrained, Cournot and leader/follower models, are reported in Table A2 of Appendix III to this paper.[15]

On the demand side, one can use the estimated parameters of the firm-specific inverse demand functions to calculate a variety of elasticities. One "very partial" demand elasticity is computed simply by solving the i^{th} firm's inverse demand equation (32) for, say, y_j, and then computing the "very partial" elasticity $\partial \ln y_j/\partial \ln p_i = (\partial y_j/\partial p_i)\cdot(p_i/y_j) = p_i/(\delta_{ji} y_j)$; other "very partial" demand elasticities for firm i can be computed analogously.

Table 5

Estimated Firm-Specific Returns to Scale, Selected Years
Based on Unconstrained and Cournot Behavioral Assumptions
(Estimated Standard Error in Parentheses)

	UNCONSTRAINED			COURNOT			LEADER/FOLLOWER		
YEAR	GM	FORD	CHRY	GM	FORD	CHRY	GM	FORD	CHRY
1959	1.384	1.767	2.446	1.410	1.926	2.506	1.406	1.894	2.491
	(.083)	(.162)	(.163)	(.084)	(.171)	(.167)	(.084)	(.162)	(.164)
1974	1.266	1.432	2.019	1.308	1.557	2.065	1.304	1.551	2.062
	(.079)	(.105)	(.097)	(.080)	(.104)	(.098)	(.080)	(.102)	(.098)
1978	1.101	1.497	1.568	1.170	1.395	1.628	1.185	1.397	1.631
	(.134)	(.261)	(.141)	(.132)	(.141)	(.147)	(.149)	(.141)	(.148)
1980	0.905	1.064	1.158	0.936	1.091	1.166	0.941	1.084	1.165
	(.071)	(.044)	(.037)	(.072)	(.044)	(.038)	(.074)	(.043)	(.037)
1983	0.633	0.758	0.753	0.647	0.817	0.768	0.652	0.817	0.768
	(.048)	(.056)	(.042)	(.048)	(.057)	(.042)	(.050)	(.057)	(.042)

These estimated elasticities, presented in Table 6 below, are very partial in the sense that they measure, for example, the effect of a price change on the quantity demanded for one firm, holding the outputs of other firms fixed as well as the other macroeconomic shift variables in the demand equations.

As is seen in Table 6, the estimated own-price very partial demand elasticities are all negative as expected, they indicate demand is elastic, and that demand is more own-price responsive for GM than for Ford or Chrysler; furthermore, while outputs from GM and Ford are highly substitutable, those between Ford and Chrysler, and GM and Chrysler, are complementary. Since both Ford and GM appear to be highly complementary with Chrysler, whose own price elasticity of demand is relatively smallest, these elasticity estimates suggest that relatively few consumers view Chrysler as their primary car, but instead view it as a secondary auto that can be used in conjunction with either Ford or GM as their primary auto.

In terms of other "very partial" output elasticities, a somewhat surprising result we have is that the demand elasticity with respect to GNP is negative, and largest (in absolute value) for GM; the elasticity with respect to the unemployment rate UN is negative, as expected, is largest (in absolute value) for GM and smallest for Ford. The demand elasticity with respect to the real interest rate INR is positive whenever INR is positive (INR is negative in 1974 and 1979), and in these cases it is considerably larger for GM than for Ford or Chrysler.

In terms of demand responses to real gasoline prices, all elasticity estimates are negative and substantial; from 1974 onward, GM's products are particularly GAS price sensitive, while Ford's are least responsive. Increases in the CPI relative to the GNP deflator, ceteris paribus, increase demand for products from all three automakers, with GM's demand being particularly responsive. Finally, the elasticity of demand with respect to the exchange rate ($/yen) is negative for all three automakers, indicating that as the US dollar depreciates, the increasingly less expensive Japanese imports provide stiff competition for domestic automakers; not surprisingly, this elasticity is largest (in absolute value) for GM, while estimates for Ford and Chrysler are approximately equal.

It is worth noting that while the results in Table 6 are based on the estimated unconstrained model, roughly similar findings occur with the Cournot and leader/follower specifications.

A basic problem with interpreting these "very partial" demand elasticities is that it is of course entirely unrealistic to expect that within oligopolistic automobile manufacturing, firms' quantities would be held

Table 6

Very Partial Output Demand Elasticities
Based on Estimated Unconstrained Model, By Firm, Selected Years

Output Quantity Demand Elasticity With Respect To:

FIRM	P_{GM}	P_F	P_C	GNP	INR	UN	GAS	CPI	EXR
GM									
1959	-16.81	5.60	-3.60	-28.67	3.31	-5.31	-8.04	28.99	-14.27
1974	-10.68	5.59	-3.00	-19.85	-1.70	-3.73	-5.65	19.68	- 7.07
1979	-12.33	4.83	-2.54	-10.82	-0.29	-2.65	-4.02	13.30	- 4.34
1983	-18.34	7.01	-3.50	-10.63	1.22	-5.26	-7.97	17.22	- 3.78
FORD									
1959	15.68	-2.37	-8.23	-2.01	0.22	-0.99	-3.15	0.44	-2.52
1974	10.44	-2.48	-7.18	-1.46	-0.12	-0.73	-1.39	0.31	-1.31
1979	15.13	-2.68	-7.65	-1.00	-0.03	-0.65	-0.91	0.27	-1.01
1983	20.32	-3.52	-9.52	-0.88	0.10	-1.16	-0.80	0.31	-0.79
CHRY									
1959	- 9.63	-5.91	-3.98	-2.57	0.68	-1.94	-8.04	0.98	-2.78
1974	- 5.83	-5.61	-3.15	-1.69	-0.33	-1.30	-3.23	0.63	-1.31
1979	- 8.96	-6.46	-3.56	-1.23	-0.08	-1.23	-2.23	0.57	-1.07
1983	-11.11	-7.81	-4.09	-1.01	0.27	-2.03	-1.82	0.61	-0.78

fixed even if one automaker changed price. Rather, as outlined in our theoretical section, profit maximizing firms would recognize their interdependent product demands, and engage in strategic pricing and markup behavior. Thus a more useful elasticity calculation is one based on a "general equilibrium" rather than a "very partial" simulation -- one in which the reduced form equations are simultaneously solved, corresponding to situations in which all three firms simultaneously optimize, setting prices, adjusting production, and varying their markups to maximize profits.

To compute these general equilibrium output prices and quantities, we first solve the three inverse demand (32) and the three profit-maximizing MR/MC markup equations (2) for the three firms' prices and quantities, using historical data on all the exogenous variables.[16] The estimated marginal costs and optimal markups for the unconstrained, Cournot and leader/follower models by firm, for selected years, are given in Table 7.[17] A number of results are worth emphasizing.

First, except for 1974, marginal costs are largest for GM under all three behavioral specifications, and are larger for Ford than Chrysler until the end of the sample, when their marginal costs are approximately equal.

Second, it is clear from Table 7 that markups vary substantially over time and among firms, indicating that diversity rather than constancy of markups characterizes the US automobile industry. Markups are uniformly larger under Cournot behavior than under unconstrained profit maximization. Notice also that in the leader/follower specification, markups for GM are larger than under Cournot, for Ford they are smaller, and for Chrysler they are very slightly larger. _A priori_, one might expect that markups under leader/follower behavior relative to Cournot conduct would be larger for the leader (GM), and smaller for both follower firms (Ford and Chrysler). The small but very slightly larger markups for Chrysler under leader/follower relative to Cournot are therefore somewhat surprising, but this result does not indicate that the estimated model is inconsistent with expectations based on theory. Rather, it is due in large part to the fact that the estimated technology and demand parameters are different in the leader/follower and Cournot models; we conjecture that if one used all the Cournot parameters and in addition constrained λ_1 according to (28) using the Cournot model estimated parameters, then profits and markups would be larger for GM and smaller for both Ford and Chrysler under leader/follower than under Cournot behavior.[18]

Table 7

Estimated Firm-Specific Marginal Costs and Markups, Selected Years
Based on Unconstrained, Cournot and Leader/Follower Behavioral Assumptions
(Standard Error in Parentheses)

YEAR	Estimated Marginal Cost (1975$) GM	FORD	CHRYSLER	Estimated Markup ($\hat{P}$ - $\hat{MC}$) (1975$) GM	FORD	CHRYSLER
			Unconstrained Generalized Profit Maximization			
1959	6941.50	4560.09	4083.75	321.45	803.96	1091.16
	(415.09)	(417.43)	(271.46)	(279.94)	(347.71)	(178.48)
1974	3631.57	4246.03	2719.10	397.46	925.03	1254.74
	(226.58)	(312.41)	(130.59)	(346.13)	(400.08)	(205.23)
1979	4307.18	3637.30	3327.64	511.20	912.77	1295.41
	(510.52)	(387.03)	(161.78)	(445.18)	(394.77)	(211.89)
1983	6168.50	4652.15	4740.48	391.02	758.55	1290.27
	(469.23)	(345.81)	(262.27)	(340.52)	(328.07)	(211.05)
			Cournot Profit Maximization			
1959	6815.27	4183.16	3984.82	480.54	1234.98	1193.26
	(406.08)	(371.95)	(265.29)	(240.79)	(264.14)	(163.12)
1974	3516.17	3905.48	2658.28	594.18	1420.97	1372.15
	(214.65)	(259.58)	(126.34)	(297.73)	(303.92)	(187.57)
1979	4069.02	3228.31	3261.60	764.21	1402.13	1416.64
	(479.67)	(325.73)	(157.14)	(382.93)	(299.89)	(193.65)
1983	6031.81	4317.45	4651.52	584.55	1165.23	1411.01
	(452.08)	(300.56)	(255.70)	(292.91)	(249.22)	(192.88)
			Leader-Follower Profit Maximization			
1959	6835.85	4254.20	4010.18	510.58	1221.02	1195.28
	(407.17)	(363.07)	(263.50)	(263.78)	(265.52)	(164.93)
1974	3525.08	3922.75	2662.53	631.31	1404.90	1374.47
	(216.68)	(258.79)	(126.26)	(326.15)	(305.51)	(189.65)
1979	4015.91	3224.01	3261.37	811.97	1386.28	1419.03
	(491.48)	(325.76)	(157.14)	(419.49)	(301.46)	(195.80)
1983	5984.92	4317.23	4651.85	621.08	1152.05	1413.39
	(461.29)	(300.60)	(255.70)	(320.87)	(250.52)	(195.02)

Third, on an absolute basis, markups are smallest for GM, and under unconstrained profit maximization, they are largest for Chrysler; when Cournot or leader/follower behavior is assumed, however, approximately equal markups occur for Ford and Chrysler for most years, with Chrysler improving relative to Ford towards the end of the sample. Since Chrysler's marginal costs are smallest for most of the sample, on a percentage basis the markups presented in Table 7 are typically largest for Chrysler and smallest for GM.

Finally, in all cases the differentials in markups between GM and the other two firms are much less than differences in marginal costs, particularly in the case of unconstrained general profit maximization. This suggests that GM may well be experiencing significant constraints upon its pricing behavior, constraints not adequately modeled using simple Cournot and leader/follower frameworks. One possibility is that we may be observing a situation in which GM sets its price and Ford and Chrysler act as a quasi-competitive fringe. In view of the uniformly higher marginal cost differentials than price differentials between GM and its rivals, this suggests that Ford and Chrysler may be adapting to GM's prices and exploiting their relative cost differentials. A detailed analysis of such Bertrand-type price-setting (rather than Cournot quantity-setting) behavior is of great interest and is currently underway, but it is beyond the scope of this paper.

In view of the high variability of the marginal cost and markup values over the sample period, it is useful to consider how output prices, output quantities, and markups have responded to supply and demand shocks that shift the cost and inverse demand functions. The cyclical nature of markup behavior has been the subject of considerable recent controversy. Although the conventional wisdom has been that in periods of slack demand, firms are more willing to cut prices to maintain market share,[19] the recent "revisionist" literature argues that in periods of booms, firms may believe that the penalties for cheating are less, and that they can better afford to cut prices to increase market share.[20]

To examine this issue more closely using our micro data, we compute reduced form general equilibrium elasticities of output price, output quantity, marginal cost and markup with respect to the exogenous macro-economic variables in the inverse demand functions. More specifically, using historical data on all the exogenous variables and our 3SLS estimated parameters, we solved the nine inverse demand, MR/MC and marginal cost equations for nine endogenous variables -- output price, output quantity, and marginal cost, for each of the three firms. We then increased one of the exogenous macro-economic variables in the inverse demand equation by 1%, obtained a new set of firms' prices, quantities, marginal costs and markups, and then computed an arc elasticity. We did this for each of the six macroeconomic exogenous variables, using parameter estimates from all three models; to conserve space, in Tables 8 and 9 we report results from these "reduced form" general equilibrium elasticity computations for only the unconstrained profit maximization model.[21] Several comments are worth noting.

First, to us the most striking finding from these tables is the diversity in elasticity estimates -- both among firms and over time. This diversity suggests that imposing constancy over time, or equality among firms on markup behavior masks substantial heterogeneity. In the top panel of Table 8, for example, we see that output quantity elasticities tend to have the same sign

Table 8

Reduced Form General Equilibrium Output Quantity and Price Elasticities
Based on Estimated Unconstrained Model, By Firm, Selected Years

FIRM	Output Quantity Elasticities with Respect To:					
GM	GNP	INR	UN	GAS	CPI	EXR
1959	1.34	0.02	0.11	-1.23	-1.03	0.99
1974	1.11	-0.01	0.09	-0.62	-0.84	0.59
1979	1.04	-0.00	0.11	-0.55	-0.98	0.62
1983	0.75	0.01	0.17	-0.40	-0.93	0.40
FORD						
1959	3.81	-0.32	0.62	-1.86	-4.63	1.18
1974	8.59	0.54	1.41	-2.56	-10.22	1.90
1979	11.36	0.22	2.44	-3.22	-16.75	2.82
1983	4.39	-0.37	1.90	-1.24	-8.52	0.97
CHRYSLER						
1959	24.48	-2.74	7.55	-10.20	-21.59	15.22
1974	-4.52	-0.37	-1.41	-1.15	3.91	-2.01
1979	-2.08	-0.05	-0.85	-0.50	2.23	-1.04
1983	-2.31	0.26	-1.90	-0.56	3.26	-1.02

	Output Price Elasticities with Respect To:					
GM	GNP	INR	UN	GAS	CPI	EXR
1959	0.05	0.00	0.00	-0.04	-0.04	-0.95
1974	0.08	-0.00	0.01	-0.04	-0.06	-0.38
1979	0.04	-0.00	0.01	-0.02	-0.04	-0.29
1983	0.02	0.00	0.01	-0.01	-0.03	-0.19
FORD						
1959	-3.07	0.26	-0.50	1.50	3.73	-0.95
1974	-1.71	-0.11	-0.28	0.51	2.03	-0.38
1979	-1.18	-0.02	-0.25	0.33	1.73	-0.29
1983	-0.85	0.07	-0.37	0.24	1.64	-0.19
CHRYSLER						
1959	0.73	-0.08	0.23	0.31	-0.65	0.46
1974	0.86	0.07	0.27	0.22	-0.75	0.38
1979	0.61	0.02	0.25	0.15	-0.65	0.30
1983	0.34	-0.04	0.28	0.08	-0.49	0.15

Table 9

Reduced Form General Equilibrium Marginal Cost and Markup Elasticities
Based on Estimated Unconstrained Model, By Firm, Selected Years

FIRM	Marginal Cost Elasticities with Respect To:					
GM	GNP	INR	UN	GAS	CPI	EXR
1959	-0.04	-0.00	-0.00	0.03	0.03	-0.03
1974	-0.06	0.00	-0.01	0.03	0.05	-0.03
1979	-0.04	0.00	-0.00	0.02	0.03	-0.02
1983	-0.02	-0.00	-0.00	0.01	0.02	-0.01
FORD						
1959	-11.59	0.97	-1.88	5.67	14.06	-3.57
1974	-3.34	-0.21	-0.55	0.99	3.97	-0.74
1979	-2.13	-0.04	-0.46	0.60	3.15	-0.53
1983	-1.64	0.14	-0.71	0.47	3.19	-0.36
CHRYSLER						
1959	2.83	-0.32	0.87	1.18	-2.50	1.76
1974	9.56	0.79	2.99	2.43	-8.27	4.25
1979	49.21	1.29	20.13	11.88	-52.77	24.64
1983	2.83	-0.32	2.33	0.68	-3.99	1.25

	Markup Elasticities with Respect To:					
GM	GNP	INR	UN	GAS	CPI	EXR
1959	1.37	0.02	0.11	-1.26	-1.06	1.02
1974	1.17	-0.01	0.10	-0.66	-0.88	0.62
1979	1.08	-0.00	0.12	-0.57	-1.01	0.64
1983	0.77	0.01	0.17	-0.41	-0.95	0.41
FORD						
1959	17.42	-1.28	2.54	-7.13	-16.38	4.92
1974	12.34	0.75	1.97	-3.52	-13.65	2.65
1979	13.78	0.27	2.91	-3.80	-12.29	3.37
1983	6.13	-0.50	2.63	-1.70	-11.36	1.33
CHRYSLER						
1959	21.05	-2.43	6.62	8.92	-19.58	13.22
1974	-12.85	-1.16	-4.28	-3.49	13.27	-6.00
1979	-34.37	-1.33	-17.47	-11.07	116.46	-20.60
1983	-5.00	0.57	-4.14	-1.23	7.56	-2.25

for GM and Ford, but these often differ from Chrysler; output quantity elasticity estimates differ in sign among automakers for the UN, CPI and EXR variables, but have the same (negative) sign in the case of GAS. The idiosyncratic 1959 estimates for Chrysler reflect in part a computational difficulty we experienced in obtaining a reduced-form solution to Chrysler's output price, output quantity and markup equations in that year.

More specifically, as seen in the top panel of Table 8, while GM's and Ford's output reacts positively to GNP, the elasticity of Ford's output is considerably larger than GM's; moreover, except for 1959, Chrysler's output exhibits a consistently large but negative elasticity of output with respect to GNP. In terms of other macroeconomic variables, GM and Ford have the same qualitative response of output with respect to UN (positive) and CPI (negative), although Ford's output responses are more volatile. The response of output with respect to EXR ($/yen) also varies by firm. When EXR increases, Japanese imports become more expensive in terms of US dollars, <u>ceteris paribus</u>, the output of GM and Ford increases (consumers view GM and Ford as being substitutes for Japanese imports), while that of Chrysler decreases (Chrysler products being complementary to Japanese imports).

Second, as seen in the bottom panel of Table 8, for all firms the reduced form general equilibrium output price elasticities are much smaller in absolute magnitude than output quantity elasticities. Moreover, in many cases these output price elasticity estimates vary in sign among automakers.

Turning to the top panel of Table 9 where we report marginal cost elasticity estimates, we again are struck by the diversity. GM's marginal costs are least responsive to macro-economic supply and demand shocks, and elasticity estimates for Chrysler often differ in sign from GM and Ford. If one interprets the marginal cost elasticity with respect to GAS as reflecting supply shocks, for all three automakers these elasticity estimates are positive, as expected.

Finally, in the bottom panel of Table 9 we report reduced form general equilibrium markup elasticities. In Appendix II to thise paper we show that even in models much simpler than ours, the predicted signs of these markup elasticities with respect to supply and/or demand shocks are often ambiguous. Thus, economic theory provides little guidance on what to expect here, and instead we must address these issues empirically. In general, we again find considerable diversity, with sign estimates being the same for GM and Ford, but different for Chrysler. In particular, for GM and Ford, we find that markup elasticities with respect to real GNP are positive, lending support to the "conventional wisdom"; such is not the case, however, for Chrysler. Hence, depending on the firm being analyzed, we find support for both the "conventional wisdom" and "revisionist" literatures. Markup elasticity estimates with respect to UN and EXR are positive for GM and Ford, and those for Ford are larger in absolute value, suggesting that Ford has a more volatile markup behavior; for Chrysler, these elasticity estimates are negative. Except for Chrysler in 1959, markup elasticity estimates with respect to GAS are always negative, suggesting that increases in real gas prices, ceteris paribus, impose substantial pressures on the profitability of all three U.S. automakers.

V. CONCLUDING REMARKS

Our purpose in this paper has been to implement empirically, using firm-specific data from the US automobile industry, a model sufficiently general to permit the testing of a variety of specific behavioral postulates associated with the strategic profit maximizing behavior of GM, Ford and Chrysler. We find that our 1959-1983 data are consistent with both a Cournot quantity-setting set of constraints, and with the restrictions implied by leader/follower behavior, with GM acting as leader; although neither set of restrictions is rejected at usual levels of significance, the constraints implied by the leader/follower model are slightly more binding than those associated with Cournot behavior. In terms of the cyclical analysis of markup behavior, our most striking result is the great diversity of behavior we find among GM, Ford and Chrysler. Depending on which firm is being analyzed, there is support for the pro-cyclical conventional wisdom of markups (GM and Ford), as well as for the counter-cyclical revisionist literature (Chrysler). Diversity, rather than constancy and homogeneity, best characterizes this industry.

Our research can be extended in a number of ways. First, we have examined only the Cournot-type quantity-setting models, and have not developed a framework for assessing Bertrand-type price-setting models. We are currently working on developing and estimating such price-setting models, and comparing them with results from this paper.

Second, data limitations have precluded us from developing a framework for introducing the strategic behavior of Japanese automakers explicitly into our analysis of the US auto market (although our inverse demand equation does account for changes in the dollar/yen exchange rate). That would seem to be a useful and informative research topic, but data issues could be somewhat difficult to overcome.

Third, although our data have been constructed with care, we well realize that the reliability of our firm-specific data series can be called into question, especially for the capital stock estimates. In this paper we have used a long-run cost function with capital price rather than capital stock as a regressor, thereby attempting to mitigate measurement error problems. A useful direction for future research would be to specify instead a short-run cost function where capital is quasi-fixed and attempt to deal directly with econometric problems associated with measurement error.

Finally, our measure of output has taken product mix into account by including an hedonic adjustment, but a more satisfying procedure would involve specifying and estimating a model in which the various sizes would be treated as distinct outputs. Because such a model would necessarily involve a considerable increase in the number of parameters to be estimated, however, its implementation would require increasing the number of observations, and thus our 1959-83 data would need to be updated, and perhaps even extended backwards before 1959.

APPENDIX I: DATA SOURCES AND DATA CONSTRUCTION

The data set for this study consists of annual data from 1959-1983, taken primarily from that originally constructed and employed by Ana Aizcorbe, Clifford Winston and Ann F. Friedlaender [1987] and extended by us. We now describe this data set and our extensions to it; a more detailed description of the original data is given in Aizcorbe, Winston and Friedlaender [1987, especially pp. 22-32].

Data on labor quantity (number of domestic employees) were available from Moody's and Standard & Poor for Chrysler and Ford, while GM provided data on its domestic employment. Annual compensation data for domestic employees of each of the automakers were obtained from the United Auto Workers.

Because data on the cost of materials purchased by domestic plants were not available, it was necessary to employ series on the materials purchases by domestic operations. Following Aizcorbe, Winston and Friedlaender, we assume that from 1959 to 1983 the ratio of domestic materials purchases to domestic sales was the same as the ratio of worldwide materials purchases to worldwide sales. To mitigate problems of double-counting and in interpreting transfer prices in these vertically integrated firms, we employed as our measure of materials prices the average cost in dollars per pound of materials purchased by each automaker.

The capital rental price measure takes taxes and expected inflation into account, as outlined in Aizcorbe, Winston and Friedlaender [1987, pp. 27-30]. Although the tax rate and expected inflation variables are common among the three firms (the latter calculated using an adaptive expectations representation), the cost of financing is firm-specific and is computed as a weighted average of the cost of borrowing and the cost of equity, where the latter is estimated using a capital asset pricing model. Based on firms' financial data from domestic operations and assuming that retained earnings approximate economic profits, total domestic costs were computed as sales minus net earnings plus dividends. The total capital costs were then calculated as total domestic costs minus labor costs and materials costs, and capital quantity was then constructed as total capital costs divided by the rental price of capital.

For each of the three firms, input prices were transformed into constant 1975$ by dividing the input price measure by the GNP deflator. Sample means, minimum and maximum values, and standard deviations for the three input price and quantity measures for each of the automakers are presented in Table 1 in the main text of this paper. There it is seen that while average materials prices were lowest for GM and highest for Chrysler, average labor and capital prices were the exact opposite, being highest for GM and lowest for Chrysler.

The output price and quantity data were constructed in two steps. First, output quantity data were obtained as the number of autos produced, with an adjustment made for calendar year vs. model year. The corresponding output. price measure was then computed as average revenue, i.e., the dollar value of sales divided by the number of autos produced.

The problem with both these measures is that they fail to take into account the changing composition of automobile production among small, intermediate and large models. Although we have a preference for specifying a model that treats these various size classes as distinct outputs, our relatively small time series of data does not permit such a rich parameterization, and thus we compromise by employing an hedonic approach that facilitates a more parsimonious parameterization.

Specifically, we ran a pooled Box-Cox regression equation for the three automakers in which a real average revenue variable (average revenue divided by the GNP deflator) was regressed on a series of annual time dummies, firm-specific dummy variables for Ford and Chrysler, and firm-specific product mix variables for Ford and Chrysler, where the latter were defined as the share of large models (gross vehicle weight greater than 3,000 pounds) in total vehicle production by firm. To avoid problems of scaling, we divided the dependent variable by the sample geometric mean. Using maximum likelihood estimation, we obtained an estimate of the Box-Cox transformation parameter equal to 2.71, with a large-sample standard error of 0.87. Note that a 95% confidence interval would barely include $\lambda = 1.00$, the traditional linear specification.

Based on this Box-Cox regression, for each observation we set the stochastic disturbance term to zero and then computed the predicted value by reversing the Box-Cox transformation,

$$\hat{P}_{it} = (\hat{\mu} \cdot X_{it}\hat{\beta} + 1)^{1/\hat{\mu}} ,$$

where $\hat{\mu}$ is the estimated Box-Cox transformation parameter. To normalize these quality-adjusted prices, we divided each $\hat{P}_{it}$ by the predicted value for GM in 1975, and thereby obtained normalized quality-adjusted real price indexes for GM, Ford and Chrysler. These price indexes are given in Table A1 below.

Finally, to obtain a consistent measure of real output quantity adjusted for compositional changes, we divided constant dollars sales by the above composition-adjusted price of output. Sample means, minimum and maximum values, and standard deviations for the output quantity, output price and product mix variables are presented for each of the three firms in Table 1 in the main text. Note that after adjusting for size composition, average car prices among automakers are approximately equal; GM's average prices are smallest while those from Chrysler are largest.[22]

Last of all, a common set of variables was specified as being exogenous to the firm-specific demand equations. These exogenous variables included real GNP, a real interest rate (INR), the unemployment rate (UN), real gasoline prices (GAS), the ratio of the consumer price index to the GNP deflator (CPI),

Table A1

Hedonic Quality-Adjusted Real Price Indexes for GM, Ford and Chrysler with GM's 1975 Size Composition as Numeraire

YEAR	GM	FORD	CHRYSLER
1959	0.9686	0.8918	0.8288
1960	0.8931	0.7867	0.7972
1961	0.8721	0.7510	0.7633
1962	0.9106	0.8136	0.8300
1963	0.8902	0.8002	0.7884
1964	0.8974	0.8392	0.7844
1965	0.9705	0.9452	0.8611
1966	0.9689	0.9488	0.8600
1967	0.9642	0.9518	0.8588
1968	0.9622	0.9346	0.8524
1969	1.0517	1.0158	0.9495
1970	0.9750	0.9429	0.8781
1971	1.0619	1.0454	0.9929
1972	1.0550	1.0377	0.9853
1973	0.9883	0.9569	0.8997
1974	0.8739	0.8651	0.7066
1975	1.0000	0.9762	0.8888
1976	0.9954	0.9643	0.8768
1977	1.0508	1.0194	0.9449
1978	1.0167	0.9989	0.9469
1979	1.0214	1.0146	0.9510
1980	1.0299	1.0304	0.9993
1981	1.0609	1.0627	1.0462
1982	1.1590	1.1309	1.1389
1983	1.1315	1.1113	1.1059

and the US-Japan exchange rate, defined as the number of US dollars per 1,000 Japanese yen (EXR). Summary statistics for these common demand variables are presented in Table 1 in the text.

APPENDIX II:

A STYLIZED FRAMEWORK FOR UNDERSTANDING CYCLICAL VARIATIONS IN MARKUPS[23]

In this appendix we present stylized models of markup behavior that assist us in interpreting empirical findings on the markup elasticity behavior of GM, Ford and Chrysler. We begin with the case of a monopolist, and then consider three types of frameworks for oligopolists.

For simplification, assume a monopolist faces a quadratic cost function and a linear demand function, and that it produces a single output y, utilizing a single input whose price is w. Write the monopolist's inverse demand function as

$$p = a - by + u \tag{A1}$$

where a and b are positive parameters, and u represents a composite exogenous demand effect. Since the cost function is quadratic, the marginal cost function can be expressed as

$$mc = cw + dy + v \tag{A2}$$

where c and d are assumed to be positive parameters and v represents a compositie exogenous supply effect independent of input prices. Thus v can be interpreted as an exogenous technological shock, while unexpected changes in w can be interpreted as input price shocks.

Assuming the monopolist acts so as to maximize profits, we obtain the following reduced-form expressions for optimal output y^*, optimal marginal cost mc^*, and the optimal price-marginal cost markup μ^*:[24]:

$$y^* = (a + u - cw - v)/(2b + d) \tag{A3}$$

$$mc^* = (2bcw + da + du + 2bv)/(2b + d) \tag{A4}$$

$$\begin{aligned} \mu^* &= (p^* - mc^*)/mc^* \\ &= by^*/(dy^* + cw + v) = b/[d + (cw + v)/y^*)]. \end{aligned} \tag{A5}$$

Notice that $dy^*/du > 0$, $dy^*/dv < 0$, while sign (dmc^*/du) = sign (dmc^*/dv) = sign $[d/(2b + d)]$. From this, we can conclude that a positive demand shock (du

> 0) will increase the monopolist's output level and markup, while a positive supply shock (dv > 0) will have the opposite effect.[25] If the monopolist is producing under increasing returns to scale, then d < 0, and the response of its output and markup to a supply or demand shock is the same as that if it produces under increasing costs (d > 0). However, the reponse of marginal costs will be affected by the returns to scale since a positive demand shock u will cause marginal costs to increase or decrease depending on whether the firm producers under increasing or decreasing costs.[26]

While the response of a monopolist to demand or supply shocks is rather intuitive, the response of oligopolists is less so. To obtain an understanding of the nature of these responses in oligopolistic markets, we find it useful to consider the behavior of duopolies using three different behavioral assumptions:[27] (i) both firms act as Cournot quantity setters; (ii) one firm acts as a leader and the other as a follower; and (iii) firms act as Cournot quantity setters in a world of asymmetric information.

(i) <u>Cournot</u>. Assume that the firms under consideration produce close substitutes y_1 and y_2, and that they each face linear demand functions of the form

$$y_1 = a_{11}p_1 + a_{12}p_2 + u_1 \tag{A6}$$

$$y_2 = a_{21}p_1 + a_{22}p_2 + u_2 \tag{A7}$$

where all a_{ij}'s are constant and u_1 and u_2 represent exogenous influences on demand. From the regularity conditions, we knoww that $a_{ii} < 0$ and $a_{ij} > 0$ $(i \neq j)$, and that $D = a_{11}a_{22} - a_{12}a_{21} > 0$. The inverse demand functions take the form

$$p_1 = (a_{22}y_1 - a_{12}y_2 - a_{22}u_1 + a_{12}u_2)/D \tag{A8}$$

$$p_2 = (-a_{21}y_1 + a_{11}y_2 + a_{21}u_1 - a_{11}u_2)/D. \tag{A9}$$

Now let each firm operate with a linear marginal cost function, having the form

$$mc_i = b_1w_i + b_2y_i + e_i \tag{A10}$$

where b_1 and b_2 are constant across firms, and e_i represents a firm-specific exogenous supply effect. Note that if the firms in the industry are producing under increasing marginal costs, then $b_2 > 0$, and conversely, if they are producing under increasing returns to scale.

If each firm acts as a Cournot quantity setter, it sets its marginal cost equal to its marginal revenue, assuming a fixed output of the other firm. Setting $mc_i = mr_i$ $(i = 1,2)$ and solving the resulting system of equations for each firm's equilibrium level of output yields the following equilibrium output levels for each firm:

$$y_1 = A_1E_1 + A_2E_2 + A_3u_1 + A_4u_2 \quad \text{(A11)}$$

$$y_2 = B_1E_1 + B_2E_2 + B_3u_1 + B_4u_2 \quad \text{(A12)}$$

where

$$E_i = b_1w_i + e_i, \quad i = 1,2$$

$$A_1 = D\cdot(2a_{11} - Db_2)/D_1 < 0$$

$$A_2 = a_{12}D/D_1 > 0$$

$$A_3 = [D\cdot(1 - a_{22}b_2) + a_{11}a_{22}]/D_1 > 0$$

$$A_4 = a_{12}(Db_2 - a_{11})/D_1 > 0$$

$$B_1 = a_{21}D/D_1 > 0$$

$$B_2 = D\cdot(2a_{22} - Db_2)/D_1 < 0$$

$$B_3 = a_{21}(Db_2 - a_{22})/D_1 > 0$$

$$B_4 = [D(1 - a_{11}b_2) + a_{11}a_{22}]/D_1 > 0$$

$$D_1 = (4a_{22}a_{11} - a_{12}a_{21}) - 2Db_2(a_{11} + a_{22}) + D^2b_2^2 \quad \text{(A13)}$$

Given these sign inequalities, we can see from (A11) and (A12) that a positive demand shock that affects one firm ($du_i > 0$) will increase the equilibrium output of both firms. By contrast, a supply shock that adversely affects the costs of one firm (e.g., $dE_1 > 0$) will lower the equilibrium output of that firm while raising the output of its competitor.[28]

While changes in the microeconomic environment can cause firm-specific demand or supply shocks, changes in the macroeconomic environment should affect both firms. Thus it is useful to analyze the response of each firm to simultaneous shifts in each firm's demand function ($du_1 = du_2 = du > 0$) and in each firm's marginal cost function ($dE_1 = dE_2 = dE > 0$). Such demand shifts could arise due to a booming economy, while supply shifts could also occur from such a boom or an exogenous increase in input prices, such as the energy price shocks that affected the US economy during the 1970's.

In the case of a demand shock, since dy_i/du_1 and dy_i/du_2 are each positive, it is clear that a general demand shock will increase the equilibrium output of both firms. In contrast, a general supply shock has an ambiguous impact, since as noted above an individual supply shock affects each firm in opposite directions. Nevertheless, there is a presumption that the impact of a general supply shock on output is negative, since

$$dy_i /dE = D(a_{ij} + 2a_{ii} - Db_2)/D_1. \tag{A14}$$

Thus, unless the cross demand effect (a_{ij}) is very large relative to the own demand effect (a_{ii}), $dy_i/dE < 0$.

It is also clear that both firms' prices will rise from a positive demand shock, since a rise in firm 1's prices due to an outward shift in its demand function will cause firm 2's demand curve to shift out due to the relative price effect. Similarly, a positive supply shock on the part of firm 1 will cause its price to rise and its output to fall. This in turn will shift firm 2's demand curve outward, causing its output and price to rise. Thus it is clear that a simultaneous demand shock will cause both firms' outputs and prices to rise. By contrast, a simultaneous supply shock will unambiguously cause both firms' prices to rise, while having a likely (but not necessarily) net reduction in their outputs. Hence, while the price effects are unambiguously procyclical in the case of both demand and supply shocks, the output effects are unambiguously procyclical in the case of demand shocks and are likely to be countercyclical in the case of supply shocks.

Let us now consider the response of markups -- $\mu^* = (p^* - mc^*)/mc^*$ -- to demand or supply shocks. In the case of this duopoly, the markup for each firm is given by the following expression:

$$\mu_i^* = (-a_{ii}/D)/[b_2 + E_i/y_i^*(E_i,E_j,u_1,u_2)]. \qquad \text{(A15)}$$

Since a positive demand shock unambiguously causes each firm's output to rise, a demand shock will also cause each firm's markup to increase. By contrast, a supply shock that raises costs will cause the markup to fall since E_i rises and y_i^* falls. If a macroeconomic boom is characterized by both positive demand and supply (input price) shocks, it follows that the net effect of such a boom on a firm's markup is ambiguous, since positive demand shocks and input price effects have opposite impacts upon each firm's markup relative to marginal costs.

It is important to note that this analysis has been based on the assumption that the firms in the industry operate under increasing marginal costs, which occurs when there are decreasing returns to scale. If firms instead operate under constant marginal costs ($b_2 = 0$), the results given above will not change since the signs of the coefficients of the equilibrium output equations given in equations (A11) and (A12) will not be affected. If, however, the firms operate under decreasing marginal costs ($b_2 < 0$), then it is generally impossible to sign the relevant expressions since the sign of the numerators containing b_2 generally becomes ambiguous.[29] Thus, we cannot derive general conclusions about the impact of supply or demand shocks in the presence of decreasing marginal costs; the effects of these shocks depend on the parameter values of the underlying cost and demand functions.

(ii) Leader/follower. Any extension of the formal analysis beyond the Cournot model quickly becomes very messy analytically. Nonetheless, we can obtain an understanding of the economic issues underlying differences between the behavior in a Cournot and in a leader/follower framework by considering a simple example. Specifically, assume that the demand functions are given by the following expressions,

$$y_1 = -4p_1 + p_2 + u_1 \tag{A16}$$

$$y_2 = 2 \cdot p_1 - p_2 + u_2, \tag{A17}$$

and that each firm's marginal cost is given by

$$mc_i = y_i + e_i, \; i = 1,2. \tag{A18}$$

In this case we can show that the Cournot equilibrium is given by

$$y_1 = (-10e_1 + e_2 + 4u_1 + 3u_2)/19 \tag{A19}$$

$$y_2 = (2e_1 - 4e_2 + 3u_1 + 7u_2)/19, \tag{A20}$$

while the leader/follower equilibrium has the form

$$y_1 = (-10e_1 + e_2 + 4u_1 + 3u_2)/18 \tag{A21}$$

$$y_2 = e_1/9 - 19e_2/90 + 7u_1/47 + 11u_2/30. \tag{A22}$$

From this we see that relative to the Cournot solution, each of the leader's coefficients are larger in absolute value, and each of the follower's coefficients are smaller. This implies, in turn, that the leader's output will be more volatile and that the follower's output will be less volatile, in response to all types of shocks. This occurs because the greater monopoly power of the leader enables it to exploit more of supply or demand shifts caused by the shock -- whether positive or negative.

(iii) Asymmetric Information. To this point we have analyzed market behavior in a world in which the various firms may be myopic, but in which the market acts as though there is full information about each firm's cost and demand functions. Typically, however, instead of there being full information about the structure of costs and demands, one finds incomplete or asymmetric information. Thus it is useful to analyze a simple example in which asymmetric information exists, and then compare it to the case in which full information occurs. We now show that the effects of demand or supply shocks on output levels and firm markups will be smoothed in the presence of asymmetric information.

To see this, consider a world of Cournot quantity setters, and let us now compare the equilibria in the presence of full and asymmetric information. Assume initially that in firm 1's marginal cost function (A10), $e_1 = 1$ and that after the supply shock $e_1 = 0$. Moreover, both firms know that $e_2 = 0$. If both firms act as Cournot competitors with full information, the equilibrium outputs turn out to be

$$e_1 = 1: \quad y_1 = (-10 + 4u_1 + 3u_2)/19 \qquad y_2 = (2 + 3u_1 + 7u_2)/19 \qquad \text{(A23)}$$

$$e_1 = 0: \quad y_1 = (4u_1 + 3u_2)/19 \qquad y_2 = (3u_1 + 7u_2)/19. \qquad \text{(A24)}$$

Thus, as a result of the fall in e_1 from one to zero, firm 1's output will rise by 10/19, while that of firm 2 will fall by 2/19.

Under asymmetric information, firm 1 knows that e_1 falls from one to zero, while firm 2 believes with probability ϕ that $e_1 = 1$ and with probability $1 - \phi$ that $e_1 = 0$. Let y_{1L} denote firm 1's output when $e_1 = 1$ and y_{1H} denote firm 1's output when $e_1 = 0$. The respective MR/MC equilibrium conditions for firm 1 are given by

$$-y_{1L} - .5y_2 + .5(u_1 + u_2) = y_1 + 1 \qquad \text{(A25)}$$

$$-y_{1H} - .5y_2 + .5(u_1 + u_2) = y_1. \qquad \text{(A26)}$$

Since an expected profit-maximizing firm 2 does not know firm 1's supply structure, it applies the following MR/MC equilibrium condition:

$$\phi(-y_{1L} - 5y_2 + u_1 + 2u_2) + (1 - \phi)(-y_{1H} - 5y_2 + u_1 + 2u_2) = y_2. \qquad \text{(A27)}$$

The solution to this Bayesian game is given as follows:

$$y_{1H} = -.5 + \phi/38 + 4u_1/19 + 3u_2/19 \qquad \text{(A28)}$$

$$y_{1L} = -\phi/38 + 4u_1/19 + 3u_2/19 \qquad \text{(A29)}$$

$$y_2 = 2\phi/19 + 3u_1/19 + 7u_2/19. \qquad \text{(A30)}$$

When $e_1 = 0$, firm 1 increases its output by 10/19 in a world of full information, while in a world of asymmetric information, it increased its output by $10/19 - .5 + \phi/38$. Since $.5 > \phi/38$, firm 1's change in output is greater in the world of full information. Similarly, in a full information environment, firm 2's output falls by 2/19 while in a world of asymmetric information its output falls by $(1 - \phi)\cdot 2/19$. Thus in both cases, a supply shock reducing the costs of firm 1 generates smaller shifts in output when there is asymmetric information, i.e. asymmetric information smooths the impacts of supply shocks on equilibrium output levels. This arises because the uninformed firm will always produce an average level of output to minimize its potential losses under asymmetric information.

Although the specific responses of output, prices and markups will vary with the specific market structure, the above analysis suggests that positive demand shocks (either firm-specific or general) will cause the output, prices and markups of all firms to rise. Similarly, a general supply shock will tend to reduce the outputs and markups of the firms in the market, while simultaneously increasing prices. By contrast, a positive supply shock to a specific firm will tend to reduce its output and markup while increasing the output and markup of its competitor. Finally, to the extent that booms are characterized by simultaneous positive cost and demand shocks, we cannot predict whether the response of the markup will be pro- or counter-cyclical. If demand shocks are large relative to cost shocks, then it is likely that markups will rise with booms. If, however, cost shocks are large relative to demand shocks, the opposite will occur. This suggests that cost inflation will generally be accompanied by falling markups, while demand inflation will generally be accompanied by rising markups.

Of course, these results must be adapted if any of the firms in the industry operate undering decreasing marginal costs and increasing returns to scale. Specifically, in such a case, the theoretical results obtained above must be qualified, since the actual market response depends on particular parameter values -- specifically, the extent of decreasing marginal costs relative to the own and cross-demand effects.

APPENDIX III

Table A2

Estimated Firm-Specific Technology Elasticities, Selected Years
Based on Unconstrained, Cournot and Leader/Follower Behavioral Assumptions

Elasticity	Model Assn.	GM 1959	GM 1974	GM 1983	FORD 1959	FORD 1974	FORD 1983	CHRYSLER 1959	CHRYSLER 1974	CHRYSLER 1983
$\epsilon_{C,MIX}$	U	1.10	0.38	-0.01	-0.89	-0.07	0.06	0.10	0.09	0.13
	C	1.12	0.39	-0.02	-0.97	-0.07	0.07	0.09	0.09	0.13
	F	1.11	0.39	-0.01	-0.94	-0.07	0.07	0.10	0.10	0.13
ϵ_{MM}	U	-0.28	-0.07	-0.21	-0.62	-0.30	-0.50	-0.21	-0.08	-0.27
	C	-0.29	-0.08	-0.23	-0.62	-0.30	-0.50	-0.20	-0.07	-0.26
	F	-0.29	-0.08	-0.23	-0.62	-0.30	-0.50	-0.21	-0.07	-0.26
ϵ_{MK}	U	0.08	0.02	0.02	-0.24	-0.04	-0.08	-0.34	-0.06	-0.18
	C	0.08	0.02	0.02	-0.24	-0.04	-0.08	-0.34	-0.06	-0.18
	F	0.07	0.01	0.02	-0.24	-0.04	-0.08	-0.34	-0.06	-0.17
ϵ_{ML}	U	0.20	0.06	0.19	0.86	0.34	0.58	0.55	0.13	0.45
	C	0.21	0.06	0.21	0.86	0.34	0.58	0.54	0.13	0.44
	F	0.22	0.06	0.21	0.86	0.34	0.58	0.54	0.13	0.44
ϵ_{MY}	U	0.92	0.79	1.32	0.77	0.67	0.99	0.77	0.63	1.44
	C	0.90	0.77	1.30	0.76	0.66	0.98	0.77	0.62	1.43
	F	0.89	0.76	1.28	0.76	0.66	0.98	0.77	0.62	1.43
$\epsilon_{M,MIX}$	U	0.95	0.48	0.39	0.58	0.20	0.12	0.80	0.35	0.13
	C	0.94	0.47	0.39	0.58	0.19	0.12	0.81	0.36	0.13
	F	0.95	0.48	0.39	0.58	0.19	0.12	0.81	0.36	0.13
ϵ_{KM}	U	0.18	0.08	0.07	-0.58	-0.10	-0.25	-0.70	-0.24	-0.64
	C	0.18	0.08	0.07	-0.59	-0.11	-0.26	-0.69	-0.24	-0.63
	F	0.16	0.07	0.06	-0.59	-0.11	-0.26	-0.69	-0.24	-0.63
ϵ_{KK}	U	-0.59	-0.18	-0.08	-0.99	-0.06	-0.18	0.11	0.02	0.04
	C	-0.56	-0.17	-0.08	-0.95	-0.06	-0.18	0.11	0.02	0.04
	F	-0.56	-0.17	-0.07	-0.94	-0.06	-0.17	0.11	0.02	0.04
ϵ_{KL}	U	0.41	0.11	0.01	1.57	0.17	0.44	0.59	0.22	0.60
	C	0.38	0.10	0.00	1.53	0.17	0.43	0.58	0.22	0.59
	F	0.40	0.10	0.01	1.53	0.16	0.43	0.58	0.22	0.59
ϵ_{KY}	U	1.09	1.54	0.82	0.36	0.12	0.25	-0.74	-0.59	-0.99
	C	1.05	1.47	0.79	0.20	0.06	0.14	-0.78	-0.61	-1.04
	F	1.03	1.45	0.77	0.19	0.06	0.13	-0.78	-0.61	-1.04

$\epsilon_{K,MIX}$	U	-0.16	-0.13	-0.03	-1.70	-0.22	-0.19	-1.06	-0.46	-0.12
	C	-0.27	-0.22	-0.06	-1.86	-0.24	-0.21	-1.14	-0.49	-0.13
	F	-0.24	-0.19	-0.05	-1.84	-0.23	-0.20	-1.12	-0.48	-0.13
ϵ_{LM}	U	0.27	0.05	0.29	2.27	0.70	1.56	1.02	0.24	1.16
	C	0.29	0.06	0.31	2.29	0.71	1.57	1.00	0.23	1.14
	F	0.30	0.06	0.31	2.29	0.71	1.57	1.00	0.23	1.14
ϵ_{LK}	U	0.24	0.02	0.00	1.74	0.13	0.39	0.53	0.10	0.44
	C	0.22	0.02	0.00	1.70	0.13	0.38	0.52	0.09	0.43
	F	0.23	0.02	0.00	1.69	0.13	0.38	0.52	0.09	0.43
ϵ_{LL}	U	-0.51	-0.07	-0.29	-4.01	-0.84	-1.95	-1.54	-0.33	-1.60
	C	-0.51	-0.07	-0.31	-3.98	-0.84	-1.95	-1.51	-0.33	-1.57
	F	-0.53	-0.07	-0.31	-3.98	-0.84	-1.95	-1.51	-0.33	-1.57
ϵ_{LY}	U	0.24	0.67	2.29	0.26	1.22	3.16	0.77	0.72	2.72
	C	0.25	0.64	2.23	0.23	1.06	2.84	0.77	0.70	2.68
	F	0.28	0.65	2.22	0.27	1.07	2.84	0.77	0.70	2.66
$\epsilon_{L,MIX}$	U	2.05	0.37	-0.60	-3.89	-0.52	0.13	-0.16	-0.16	0.33
	C	2.17	0.42	-0.62	-4.06	-0.51	0.17	-0.13	-0.14	0.32
	F	2.13	0.41	-0.60	-3.98	-0.50	0.16	-0.10	-0.12	0.32

Note: U refers to unconstrained profit-maximizing behavior, C to the Cournot and F to the leader/follower profit-maximizing behavioral assumption.

FOOTNOTES

[1]For example, Appelbaum [1979], Porter [1985], Bresnahan [1981] and Sullivan [1985] have tended to focus on general industry or product behavior, while Gollop and Roberts [1979] and Suslow [1986] have focussed more on firm behavior. For an empirical analysis of the railroad industry incorporating dynamic behavior, see Green and Porter [1984] and Porter [1983,1985].

[2]For other studies of the automobile industry, see Timothy Bresnahan [1987,1981], Ann F. Friedlaender, Ernst R. Berndt and Hua He [1987], and Melvyn Fuss and Leonard Waverman [1985,1986].

[3]See Jean Tirole [1988], especially chapters 5 and 6, for a discussion of dynamic games and their relationship to static behavioral oligopoly models.

[4]We treat firms as quantity setters for empirical convenience and the ease that formulating the problem in this fashion provides in interpreting the estimated coefficients and parameter constraints. Research on price-setting (Bertrand) behavior is currently in process. It is also worth noting that since firms usually use price rather than output as a strategic variable, it is useful to envisage quantity competition as really being a form of capacity competition, in which firms use capacity rather than output per se as a strategic variable. In such a case, the profit function can be viewed as a reduced form, once price competition has been "solved out". For a more complete discussion of these issues, see Tirole [1988, chapter 5], Kreps and Scheinkman [1983] and Deneckere and Davidson [1985].

[5]Specifically, within the automobile industry, model changes occur on a yearly basis, and product runs are typically reassessed throughout the year.

[6]For example, firms' objective functions might contain additional arguments such as net worth, or be characterized by a long-term dynamic view of profitability rather than a short-term static view.

[7]Unlike a simple quadratic approximation, a normalized quadratic approximation satisfies the condition that the cost function is homogeneous of degree one in factor prices. The normalized quadratic function is discussed in Daniel McFadden [1978], has been implemented by Ernst R. Berndt, Melvyn Fuss and Leonard Waverman [1980] and by Catherine J. Morrison and Ernst R. Berndt [1981]; its curvature and flexibility properties have been assessed by W. Erwin Diewert and Terence J. Wales [1987].

[8]The analysis of Bertrand-type price-setting behavior is beyond the scope of this paper, but will form the basis of a subsequent research project.

[9]In the case of a pure monopolist (and deleting i-subscripts), the MR/MC condition analogous to (20) is given by $P = \alpha_y + \alpha_{yy}y + \sum_s \alpha_{sy} w_s + \lambda y$, where $\lambda = -\delta$. Here δ represents the own-price effect in the inverse demand function. For an empirical implementation of such a monopolistic model using aggregate industry data, see Morrison [1988,1990]. Note that in the Cournot case, each oligopolist acts as though it were a monopolist operating in its given market, where the own price effect δ_{ii} represents the firm inverse demand function as opposed to the true monopolist inverse demand function δ.

[10]This approach has been used by, among others, Appelbaum [1982], Bresnahan [1987], Porter [1983,1985] and Lee and Porter [1984], although Porter has

explicitly introduced dynamic considerations. For aggregate analyses of dynamic changes in monopoly power, see Hall [1986], Rotemberg and Saloner [1986], and Morrison [1988,1990].

[11] In an interdependent market such as the automobile industry, firms will form expectations of other firms' endogenous output price, quantity and markup variables. By using the 3SLS estimation procedure, we ensure that the conjectured variations in our estimated model are consistent with the rational expectations hypothesis. For further discussion, see Lars P. Hansen and Kenneth Singleton [1982].

[12] Note that when the constraints involve cross-equation restrictions, as they do for both these tests, it becomes more difficult to assign restrictions to specific equations. To check on the ability of our overall model to reject hypotheses, we tested the null hypothesis that parameters of the inverse output demand, input demand, and MR/MC equations were equal for GM, Ford and Chrysler; the alternative hypothesis is the unconstrained profit maximization model summarized in Table 2. We obtained a Wald test statistic of 1637.747, with the .01 chi-square critical value for 52 restrictions being about 78.6; hence this null hypothesis is decisively rejected. Incidentally, we also specified a behavioral model in which total collusion reigned and in which the three firms were treated as distinct plants producing substitutable outputs, but owned by a single monopolist. The MR/MC conditions obtained by maximizing the sum of profits for GM, Ford and Chrysler with respect to these three outputs turned out to be a slight generalization of (20) in which, for the i^{th} output, $\bar{P}_i - \bar{MC}_i = \sum_j \lambda_{ji} Y_j$, where $\lambda_{ji} = -\delta_{ji}$, i,j = GM, Ford and Chrysler. We estimated models with and without the $\lambda_{ji} = -\delta_{ji}$ restrictions imposed and tested their empirical validity using the Wald test procedure; the test statistic for the 9 restrictions was 105.256, while the .01 chi-square critical value is 19.679; hence the null hypothesis is decisively rejected. We conclude that our model has sufficient goodness of fit and power to reject hypotheses, and that our result that the restrictions implied by Cournot and leader/follower behavior are consistent with the data is a meaningful one.

[13] Not surprisingly, 3SLS parameter estimates from the estimated leader-follower model do not vary dramatically from those reported in Tables 2 and 4.

[14] For example, the index of industrial production for motor vehicles and parts increased 28.4% from a level of 66.8 in 1982 to 85.8 in 1983 (1977 = 100). Source: Economic Report of the President 1990, Table C-50, p. 350.

[15] One result of particular interest here is that for GM and Ford, the elasticity of cost with respect to product mix becomes closer to zero towards the end of the sample period, indicating that for these firms, cost become less sensitive to product mix (the share of large vehicles in total production). This may reflect the general downsizing of the fleet due to CAFE standards, and thus the relative homogenization of US automobile production.

[16] Note that one might interpret the numerical iterative steps toward solving out this system of nonlinear equations as corresponding to a process in which market participants adjust quantities until a Nash equilibrium is attained.

[17] These dollar values have been computed by reversing the normalization procedure used for estimation, and multiplying the transformed prices and costs by the price of labor. Thus the values should be interpreted as being in units of 1975$.

[18] Notice that since returns to scale are not constant, what happens to markups

for the leading firm is not precisely clear when behavior changes from Cournot to leader/follower. However, profits for the leader firm should be larger under leader/follower behavior.

[19]For a discussion and elaboration of this conventional wisdom on cyclical markup behavior, see F. M. Scherer [1980].

[20]For a discussion of the revisionist hypothesis, see Julio Rotemberg and Garth Saloner [1986]. Mark Bils [1989] has argued that the revisionist hypothesis might be particularly plausible for durable goods manufacturers, such as automobiles.

[21]Estimates of these reduced form general equilibrium elasticities are roughly similar under the Cournot and leader/follower specifications.

[22]Before the hedonic adjustment, average output prices for GM, Ford and Chrysler were $5899.35, $5493.06 and $5390.90, respectively, while average output quantities were 4.94, 2.67 and 1.30.

[23]This appendix owes a great deal to Hua He, who developed the examples and wrote a first draft of it.

[24]There is some ambiguity in how one defines the percentage markup. Although some literature defines it in terms of markup relative to price, we express the proportional markup relative to marginal cost. This is done for analytical simplicity, and should not change the qualitative nature of our findings.

[25]Further, a shift in w can also be viewed as an exogenous shift in supply. This has the same effect on equilibrium as that of a shift in v, except that the effect is multiplied by the positive parameter c.

[26]For the monopolist to be in equilibrium, $2b + d > 0$. This follows because the marginal cost function must intersect the marginal revenue function from below, implying that $2b > |d|$ in the presence of increasing returns to scale.

[27]The duopoly case is analytically relatively simple and tractable. Generalization to an n firm oligopoly is possible, but the principal results of interest to us can be obtained within the much simpler duopoly framework, and therefore we confine our attention here to such a simple market.

[28]A demand shock could come about from, for example, the introduction of an improved product or an enhanced marketing program. A supply shock that increased costs to a single producer could emerge from, for example, a shift in supplier relationships or differential union behavior. Conversely, firm-specific supply shocks that reduced costs could be due to, for example, a new innovation or differential technical progress.

[29]Just as in the monopolist case, in the oligopoly case stability conditions require that $|2a_{ii}/D| > |b_2|$. This is sufficient to ensure that $D_1 > 0$ even if the firms in the industry produce under increasing returns to scale.

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