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COSTS, TECHNOLOGY, AND PRODUCTIVITY

IN THE U.S. AUTOMOBILE INDUSTRY

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Abstract

This paper analyzes the structure of costs, technology and productivity in the U.S. automobile industry by estimating a general hedonic joint cost function for domestic automotive production for the Big Three American automobile producers: General Motors, Ford, and Chrysler. In general it is found that costs are highly sensitive to the scale and composition of output, with General Motors and Chrysler experiencing an output configuration that exhibits increasing returns to scale and economies of joint production. On the other hand, Chrysler's recent productivity growth is found to be far below that of General Motors'. Although Ford's cost structure is not as advantageous as General Motors', its recent productivity growth suggests that it can remain an effective competitor in the domestic automotive market.

I. Introduction and Overview

The automobile industry has traditionally played a major role in the U.S. economy. The four domestic firms currently producing vehicles respectively represent the second largest (General Motors), the fourth largest (Ford), the seventeenth largest (Chrysler) and the one-hundredth and ninth largest (American Motors) industrial concerns in the United States.[1] Direct employment in automobile production totaled 1.5 million in 1979, exclusive of the additional employment in dealer systems, parts suppliers and/or materials, and the auto-related service industries (e.g., stereos, car washes, etc.). Moreover, activities undertaken by the auto industry have a direct effect upon energy consumption, air quality, traffic safety, and the urban and intercity transportation systems.[2]

In spite of its historical (and recent) premier position in American industry, the U.S. auto industry is currently in a state of flux. Not only is the Chrysler Corporation perilously close to bankruptcy, but Ford and General Motors have sustained unprecedented losses in the past year.[3] Moreover, Renault of France has recently bought a major interest in American Motors, making it an effective subsidiary of the French company. In addition, imports (particularly Japanese) have managed to achieve substantial penetration of the domestic market (approaching 30 percent), apparently indicating that the domestic producers have not been able to respond effectively to recent changes in consumer tastes. Thus, one of the crucial questions facing the domestic automobile producers is to what extent are their problems due to an unanticipated change in tastes toward small, fuel-efficient cars, and to what extent are they due to basic structural changes in comparative advantage that cannot be easily corrected.

To be sure, a full answer to this question requires an analysis of present and future demands for different types of automobiles as well as the present and future costs of production in the United States and abroad. While considerable empirical work has already been undertaken with respect to the demand for automobiles[4] and comparative labor costs and productivity,[5] there has been relatively little empirical work on the underlying technology of the automobile industry. However, without having a thorough understanding of the nature and extent of economies of scale, economies of multiple or joint production, and the nature and extent of productivity growth, one cannot satisfactorily assess many of the recent developments in the industry.

For example, over the past few decades there has been increasing concentration as many small producers have either merged or gone bankrupt.[6] More recently, there is some evidence of increasing specialization and emphasis on the production of fewer models and even some attention to producing a "world" car instead of the diverse product lines that have typified American production. Thus, there are some indications that the world auto industry could evolve toward a number of quasi-specialized companies concentrating on particular classes of automobiles. In such a scenario, for example, Toyota and Ford might specialize in "world" car production, while Mercedes and BMW would concentrate on high-performance autos. Countering this phenomenon, however, is the trend to diversified product and production technologies utilizing diesel and gasoline engines, robotics, electronic systems, plastics, etc.

The lack of specific quantitative information concerning the cost advantages associated with different ouptut levels and types of product combinations suggests that it would be desirable to perform an empirical analysis addressing this issue. Fortunately, recent developments in the economic literature concerning the behavior and technology of multiproduct firms provide a vehicle for such an analysis.[7] In spite of formidable data problems, this paper presents an initial attempt to analyze the structure of costs and technology of the U.S. automobile industry and to assess the nature of its size-related economies and productivity growth. Hopefully, the approach taken here can be extended to analyze the behavior of foreign producers.

This paper takes the following form. Section II presents an overview of the institutional organization and characteristics of the automobile industry. Section III develops the analytical framework that is used to guide the empirical analysis and describes the data base. Section IV discusses the empirical results and Section V presents a summary and the policy implications of the analysis.

II. Institutional Organization and Characteristics of the Automobile Industry

Since the development of the organizational structure of the automobile industry has been well documented by Abernathy (1978), this section focuses on the elements that should be included in a characterization of technology. While something of an oversimplification, it seems reasonable to characterize the industry as a marriage of two related concepts: one developed by General Motors, which stresses the production of a large number of different types of cars to appeal to all types of consumer tastes; and one developed by Ford, which streses the economies associated with large-scale production of a standard line of vehicles. Consequently, during the last 50 years domestic automobile manufacturing has been characterized by large-scale production in conjunction with a wide range of differentiated products.[8] In other words, domestic automobile production appears to have been organized to exploit both economies of scale (which refer to economies of mass production) and economies of scope (which refer to economies of joint production or multiple outputs.)

While this characterization of the industry is useful as a general guide, a full characterization of the industry's technology requires specific consideration of the nature of output, the production and planning processes, and the relationships between prices, outputs, and costs.

From the point of view of the consumer, the basic unit of production is the car, which is classified by make (e.g., Chevrolet) and the model (e.g., Malibu). In terms of demand, the relevant unit of output is a specific automobile characterized by specific attributes (trim, air conditioning, power steering, etc.) within a given make or model. From the point of view of the producer, however, the unit of output is considerably more general.

Not only are the same dies used to produce parts for a wide range of different models and makes, but parts and major components such as engines are often interchangeable as well.[9] Therefore, from the point of view of production, it seems reasonable to define output in terms of broad product lines (e.g., luxury, full-size, compact, subcompact, etc.) each of which has a range of generic attributes (e.g., wheelbase, weight, engine displacement, etc.).

In terms of production, the activities are not homogeneous, but are composed of stamping, casting, machining, and assembling, with the latter activity being the fundamental characteristic of automobile manufacturing. Thus, many automobile producers are primarily limited to the assembling process (Volvo), while firms that do not assemble parts into the final products would have to be classified as suppliers to the industry. Nevertheless, within the industry, there are varying degrees of vertical integration. General Motors has its own divisions that provide a major portion of its stamping, casting, and machining services internally, while American Motors purchases a significant share of these from outside suppliers. Consequently, in assessing the costs and technology of the firms in the industry, it is useful to consider the degree of vertical integration and the individual firms' relative demands for parts and/or materials inputs.

With respect to the utilization of plant and equipment, the industry is characterized by long planning horizons and extremely large fixed costs associated with the introduction of new car designs. Thus, whenever a new type of car is introduced, there is a long process involving design, prototype construction, testing and evaluation, designing and manufacturing of the production machinery and equipment, and the final production of the new automobile. For example, the introduction of the current new line of front-wheel drive automobiles by the American automobile manufacturers typically required a 3- to 4-year planning horizon and enormous amounts of capital. This long lead time and the associated massive investments consequently introduce a large amount of risk and wide variability in the utilization of capital stock. Since the capital used in production is typically quite long lived, this implies that automobile manufacturers may not be at a point of long-run cost minimization in which all factors are adjusted in an optimal fashion to minimize costs.[10]

Finally, it is important to note that the domestic automobile industry prior to 1979 or 1980 could be characterized as a tight oligopoly, with General Motors recognized as the dominant firm. While there is little formal knowledge of the actual market behavior of the firms in the industry, the available evidence suggests that General Motors set a price that it thought would protect its market share, and the other producers followed accordingly.[11] In terms of estimating the structure of technology, this implies that although General Motors simultaneously determined outputs, prices, and marginal costs, the other firms primarily acted as price followers with respect to G.M. Hence, this suggests that it is appropriate to treat General Motors' outputs as endogenous arguments in the cost function. It is also recognized, however, that since the bulk of the remaining outputs must be allocated between Ford and Chrysler, that one of these firms will determine its outputs, given General Motors' prices, by the location of its marginal cost curves, while the other will supply the remaining outputs. In this paper, we therefore argue that the outputs of the larger firm, Ford, should also be treated as endogenous, while those of Chrysler should be treated as exogenous.

In short, this brief survey of the automobile industry provides the following guidelines for modeling the structure of technology: (1) output should be defined in terms of a relatively small number of generic product types; (2) because of varying supplier relationships, the degree of vertical integration should be taken into consideration; (3) because of the long planning horizon and the long life of capital used to produce different types of cars, capital of diffferent vintages should probably be treated as a fixed factor; (4) in view of the determination of prices and outputs in the industry, it is probably reasonable to treat the output of firms other than Chrysler as being endogenously determined.

III. Conceptual Framework, Data, and Variables

Although there have been many studies analyzing the costs of automobile production,[12] each one has either assumed production can be characterized by a single homogeneous output or has analyzed the issue of scale economies at the plant level. Since, however, the automobile manufacturers produce a wide variety of outputs and since there may be economies related to the scale of operations or the composition of output at the firm level, it is desirable to analyze the costs and technology of automobile production using the firm (instead of the plant) as the basic unit of observation in the analysis. This permits the evaluation of organizational economies that may be related to the size of the firm and its composition of output as well as purely technical economies that may be related to the scale of operation of a particular plant.

The general hedonic cost function to be used in this analysis can be written as:[13]

$$C = C(\Psi(Y,q),w,t,T) \tag{1}$$

where: C = total costs

Ψ_i = generic level of the i^{th} output

Y_i = physical level of the i^{th} output

q_i = qualities associated with the i^{th} output

w = vector of factor prices

t = vector of technological conditions[14]

T = time variable[15]

In recent years a large literature has developed utilizing a wide variety of second-order approximations to estimate the general cost function given in equation (1).[16] In this analysis, we utilize a quadratic approximation, which represents a second-order Taylor's approximation around the mean. We thus write the cost function as:

$$C = \alpha_0 + \sum_i \alpha_i(\psi_i-\bar{\psi}_i) + \sum \beta_j(w_j-\bar{w}_j) + \sum\gamma_h(t_h-\bar{t}_h) + \delta_T(T-\bar{T})$$

$$+ 1/2(\sum_i \sum_m A_{im}(\psi_i-\bar{\psi}_i)(\psi_m-\bar{\psi}_m) + \sum_j \sum_n B_{jn}(w_j-\bar{w}_j)(w_n-\bar{w}_n)$$

$$+ \sum_h \sum_\ell C_{h\ell}(t_h-\bar{t}_h)(t_\ell-\bar{t}_\ell) + D_{TT}(T-\bar{T})^2) + \sum_i \sum_j E_{ij}(\psi_i-\bar{\psi}_i)(w_j-\bar{w}_j)$$

$$+ \sum_i \sum_h F_{ih}(\psi_i-\bar{\psi}_i)(t_h-\bar{t}_h) + \sum_i G_{iT}(\psi_i-\bar{\psi}_i)(T-\bar{T})$$

$$+ \sum_j \sum_h H_{jh}(w_j-\bar{w}_j)(t_h-\bar{t}_h) + \sum_j J_{jT}(w_j-\bar{w}_j)(T-\bar{T})$$

$$+ \sum_h K_{hT}(t_h-\bar{t}_h)(T-\bar{T}) + \varepsilon_c \qquad (2)$$

where $A_{im} = A_{mi} \ \forall i,m$

$B_{jn} = B_{nj} \ \forall n,j$

$C_{h\ell} = C_{\ell h} \ \forall h,\ell$

and ε_c represents a disturbance term.

For purposes of estimation, we must also specify the generic (hedonic) function. To economize on the number of parameters, we assume that this can be represented by a simple linear approximation and write

$$\psi_i = y_i + \sum_r a_{ir}(q_{ir}-\bar{q}_{ir}) \ . \qquad (3)$$

Thus when equation (3) is substituted into equation (2), we obtain the complete general specification of the cost function used in this analysis.

Using Shepherd's lemma, we derive the following factor demand equation for the j^{th} factor.

$$X_j = \frac{\partial C}{\partial w_j} = \beta_j + \sum_n B_{jn}(w_n - \bar{w}_n) + \sum_i E_{ij}(\psi_i - \bar{\psi}_i)$$

$$+ \sum_h H_{jh}(t_h - \bar{t}_h) + J_{jT}(T - \bar{T}) + \varepsilon_j \ , \qquad (4)$$

where ε_j represents the disturbance term. Since the error terms of the cost and factor share equations are correlated, it is desirable to estimate the factor demand equations jointly with the cost function to increase the efficiency of the estimates.[17]

In order to implement empirically this specification of technology, it is necessary to consider the quality of the available data and the institutional points raised in Section II. Thus we now turn to a discussion of our data base and then present the specifcation used in the empirical analysis.

A. Data and Variables

The data base used for this analysis is a pooled cross section, time series sample of the "Big Three" domestic automobile manufacturers: General Motors, Ford, and Chrysler,[18] for the period 1955-1979. Although these companies exhibit substantial difference in organizational structure, their production technologies are sufficiently similar to analyze them as if they shared a common technology.[19]

The analysis in the previous section indicated that capital is long lived and not particularly adaptable to production other than that for which it was planned. This indicates that it might be appropriate to estimate a short-run cost function whose dependent variable would be the noncapital variable costs of production and whose arguments would contain measures of physical capital of varying vintages. Unfortunately, however, data are not available to permit this analysis. Not only are costs available only on an aggregate basis, but there are also no data available on the stock of physical capital utilized by the automobile firms. We consequently had to utilize a long-run cost function in the analysis. From a theoretical viewpoint, this is equivalent to assuming that the automobile firms are able to adjust their capital stock in an optimal fashion on an annual basis. While such "fine tuning" is probably not possible, substantial changes in investments and scrappage do occur on an annual basis, indicating that the assumption of optimal adjustments in the capital stock may not be totally unrealistic.

The data on costs used in the analysis comes from the firms' annual reports and hence include costs of foreign and nonautomotive operations. However, the available data on factor prices reflects only those of domestic production, which created a serious errors-in-variables problem when the full joint cost function was estimated. Consequently, it was assumed that domestic production and foreign and nonautomotive production were nonjoint, and a cost function was estimated for domestic automotive production alone.[20] To this end, we constructed a series of domestic production costs based on a recent analysis by Sanford C. Bernstein Co. (1979)[21] of the costs of domestic and foreign operations.[22]

Output was initially divided into six categories according to the general market classifications:[23] luxury cars, full-size cars, compact cars, subcompact cars, truck production, and a residual, representing tractor production, changes in inventory, and nonautomotive production.[24] However, when the estimation was undertaken, it was found that the range of output was sufficiently variable that the approximation deteriorated. Hence further aggregation was used and the following three output variables were used in the analysis: compact and subcompact cars, full-size and luxury cars, and trucks.

The hedonic quality attributes should reflect the intrinsic characteristics of the output that affect production costs rather than superficial attributes that might affect consumer demand. This suggests that engineering aspects of the automobile such as type of drive system, wheelbase, engine and suspension are more relevant than, say, accessories, trim and the like.[25] In this analysis we included three attributes to reflect the intrinsic nature of the car: wheelbase, weight, and cylinder capacity.[26]

Although automobile production is a highly complex activity involving many refined types of inputs, data limitations forced us to follow a rather aggregate approach and include the following three factors in the analysis: labor, capital, and materials. As indicated above, although it would have been desirable to treat capital as a fixed factor (incorporating different vintages), data were not available to permit this. We thus treated capital as a variable factor and used the expected return of a firm's assets, including its bonds and stocks, as its price. The expected return of the stock was estimated with the capital-asset pricing model, while we calculated a weighted average of the interest on long-term debt to represent the expected return of the bonds. Labor costs were estimated as the average hourly wage of domestic labor (including fringe benefits). Finally, lacking data on the materials inputs actually used in production, we used the price of steel plate per ton as a proxy.[27]

The technological variables used in the cost function should not only include variables that indicate organizational differences among the firms, but also variables that reflect exogenous shifts in the production technology that might not be captured by the time variable alone. We have already argued that a variable reflecting the degree of vertical integration should be incorporated to capture differences in the degree to which the firm concentrates on assembling.[28] In addition, since auto producers typically produce a range of nonautomotive products (particularly defense related), it would be useful to incorporate a variable to reflect the percentage of revenues arising from automotive operations. Since data reflecting interfirm organizational differences are not readily available, a reasonable proxy is the use of simple firm-specific dummy variables. Thus, in addition to using auto sales as a percentage of total sales in the analysis, we have also used dummy variables to capture possible interfirm organizational differences.[29]

In addition to reflecting organizational structure, the technological variables could also be used to reflect basic changes in the technology that could not be captured by the time variable alone. This is particularly true for nonsystematic changes in the production function. In this respect, the increased degree of governmental regulation--particularly with respect to emissions--is significant, since the industry has vociferously claimed that emissions controls have increased costs substantially. To measure this effect we, therefore, constructed a variable to reflect the percentage reduction in the target emissions level that was mandated each year. Further, to capture the extent to which foreign competition may stimulate technical change, we utilized the number of foreign models sold in the United States as a technological variable.

B. Final Specification

Initial attmepts were made to estimate the cost function given in equation (2) with the full complement of technolgoical variables and a full range of outputs. However, given the limited number of observations (75), we encountered severe problems attributable to the limited degrees of freedom. Although aggregation into three output types helped the econometric estimation, problems still existed with including the range of technological variables. Apparently, the output variables captured most of the organizational effects, and the time trend captured any effects of technological change or shifts in the cost function induced by regulation. Thus, the final estimation omitted the technological variables. In addition, since the interaction terms of the hedonic variables with outputs and factor prices proved to be consistently statistically insignificant, they were dropped. Thus the final estimating cost equation and its associated factor demand equation took the following form:

$$
\begin{aligned}
C = \alpha_0 &+ \sum_i \alpha_i (y_i - \bar{y}_i) + \sum_j \beta_j (w_j - \bar{w}_j) + \sum_i \sum_\ell \gamma_{i\ell} (q_{i\ell} - \bar{q}_{i\ell}) + \delta_T (T - \bar{T}) \\
&+ 1/2 \sum_i \sum_m A_{im} (y_i - \bar{y}_i)(y_m - \bar{y}_m) + 1/2 \sum_j \sum_n B_{jn} (w_j - \bar{w}_j)(w_n - \bar{w}_n) \\
&+ 1/2\, D_{TT} (T - \bar{T})(T - \bar{T}) + \sum_i \sum_j F_{ij} (\bar{y}_i - \bar{y}_i)(w_j - \bar{w}_j) \\
&+ \sum_i \sum_\ell D_{i\ell T} (q_{i\ell} - \bar{q}_{i\ell})(T - \bar{T}) + \sum_i D_{iT} (y_i - \bar{y}_i)(T - \bar{T}) \\
&+ \sum_j D_{jT} (w_j - \bar{w}_j)(T - \bar{T}) + \varepsilon_c \qquad (5)
\end{aligned}
$$

$$X_j = \frac{\partial C}{\partial w_j} = \beta_j + \sum_n \beta_{jn}(w_n - \bar{w}_n) + \sum_i F_{ij}(y_i - \bar{y}_i) + D_{jT}(T-\bar{T}) + \varepsilon_j \ , \qquad (6)$$

where $A_{im} = A_{mi}\ \forall i,m$; $B_{jn} = B_{nj}\ \forall n,j$; and ε_c and ε_j represent the error terms for the cost equation and the j^{th} factor demand equation, respectively. Table 1 presents a list of the specific variables used in this analysis, while Table 2 presents their means and standard deviations.

Before turning to the estimation results, it is useful to consider the economic interpretation of the coefficients. The marginal cost of output i is given by

$$MC_i = \frac{\partial C}{\partial y_i} = \alpha_i + \sum_m A_{im}(y_m - \bar{y}_m) + \sum_j F_{ij}(w_j - \bar{w}_j) + D_{iT}(T-\bar{T}) \ . \qquad (7)$$

Thus each α_i represents the marginal cost of output type i, evaluated at the mean output levels, factor prices, and time period. Since the change in marginal cost with respect to output ($\partial MC_i/\partial y_j$) is given by the A_{ij} coefficients, these can be either positive or negative. $A_{ij} < 0$ implies weak cost complementarity, while $A_{ij} > 0$ implies no weak cost complementarity. A_{ii} can be $\gtrless 0$ depending on whether marginal costs are rising or falling. The change in marginal cost with respect to factor prices ($\partial MC_i/\partial w_j$) is given by F_{ij} and should be positive since increases in factor prices should cause the cost function to rise. Finally, the change in marginal cost with respect to time ($\partial MC_i/\partial T$) is given by D_{iT} and could be positive or negative depending upon whether the pure time-related changes in marginal costs are rising or falling. Since this also reflects the output-related change in productivity, a negative value of D_{iT} implies that technical change increases with the scale of output.

Equation (6) gives the j^{th} factor demand equation and indicates that each β_j represents the demand for factor j when all the other variables are evaluated at their mean, and should therefore be positive. Since $\partial X_j/\partial w_i$ represents the change in demand for factor j with respect to the price of factor i, B_{jn} can be positive or negative, depending on whether factors j and n are complements or substitutes. Since the own price effects should be negative, however, each B_{jj} should be negative. The F_{ij} coefficients reflect the change in factor demand with respect to each output ($\partial X_j/\partial y_i$) and should be positive since additional output is not a free good and requires more inputs.[30] Finally, the change in the demand for the j^{th} factor with respect to time ($\partial X_j/\partial T$) is given by D_{jT} and should be positive or negative according to the direction of the j^{th} factor's augmented technical change.

Since the interaction terms between quality attributes and the other variables have been restricted to zero, the $\gamma_{i\ell}$ coefficients reflect the change in costs with respect to each attribute: wheelbase, weight, and engine size of each type of output, evaluated at the mean time period. Since these variables represent technological conditions associated the production, they could be positive or negative. Finally, the $D_{i\ell T}$ variables represent the change in these costs with respect to time and can also be positive or negative, depending on the nature of technical change.

IV. Empirical Results

As pointed out in Section II, General Motors' and Ford's outputs can not be assumed to be exogenous. Consequently, each of their outputs was instrumented.[31] Then, using the data base described in Section III, Equations (5) and (6) were estimated by Zellner's seemingly unrelated regression procedure.

The parameter estimates pertaining to the domestic cost system are presented in Table 3. As can be seen, the parameters have the expected sign with the exception of the coefficients for w_1y_1 and w_1y_3, which are insignificant. In addition, the magnitudes of the coefficients are reasonable; in particular the estimated marginal costs of $2,264, $4,282, and $5,499 respectively associated with the production of small cars, large cars, and trucks at the sample mean, seem quite plausible.

The parameter estimates can be used to calculate several measures that pertain to the technology and productivity of the U.S. automotive firms, including elasticities of substitution, multiproduct economies of scale, economies of scope, and productivity growth. The elasticity of substitution of two inputs, r and s, is equal to

$$\delta_{rs} = \frac{d\ \ell n(\frac{X_r}{X_s})}{d\ \ell n(\frac{w_r}{w_s})} = \frac{CC_{rs}}{C_r C_s}, \qquad (8)$$

where the subscripts pertaining to the total cost, C, denote partial derivatives. The estimates of the elasticities of substitution (at the point of approximation) are presented in Table 4. The results indicate that labor and capital, and labor and materials are complements, while capital and materials are substitutes. In addition, the demand for each factor (with the exception of materials) is quite responsive to changes in its price. In the case of the demand for capital, this result is particularly important since it suggests that our assumption that firms are in long-run, as opposed to short-run, equilibrium may not be unreasonable.

The estimated coefficients can also be used to calculate the multi-product degree of scale economies at a given point of production. As shown by Panzar and Willig (1977), this measure is given by the following expression:

$$\hat{S}_m = \frac{C(Y)}{\sum_i \bar{Y}_i \frac{\partial C}{\partial Y_i}} . \qquad (9)$$

This will be greater or less than one as economies or diseconomies of scale exist; a value of one represents constant returns to scale.[32]

Table 5a presents the estimated returns to scale facing a "typical" firm producing at the sample mean and the most recent time-period in our sample, 1979, and each of the domestic automobile firms producing at their respective sample means and in 1979. These figures are interesting and indicate a wide diversity in estimated returns to scale. Thus while the "typical" firm, at the sample mean, appears to produce under constant returns to scale, Chrysler and General Motors appear to be subject to increasing returns, while Ford is subject to decreasing returns. Thus if Chrysler and General Motors were to increase the output of all of their product lines simultaneously while maintaining the same product mix, they would find that their costs rose less than proportionately, while Ford's costs would rise more than proportionately if it increased production in the same manner. These qualitative findings remain unchanged when we just consider the 1979 period. However, the results for the 1979 period are quantitatively striking in that they indicate that Chrysler's recent cut-back in production has prevented it from exhausting a substantial amount of its potential scale economies.

The difference in the estimated scale economies among the firms in the sample is striking and also somewhat counterintuitive in terms of the less sophisticated single-output analysis, which argues that scale economies tend to diminish with firm size. That is, although these empirical results indicate that the smallest firm could enjoy further economies by expanding its scale of operations, this appears to be true for the largest firm as well.

The reasonableness of this result can be understood by re-estimating the degree of multiproduct scale economies that would accrue to Ford and Chrysler if they produced at their observed scale of output but were able to utilize General Motors' product mix, hedonic attributes and factor prices.[33] As can be seen in Table 5b, both Ford and Chrysler would exhibit economies of scale if they were able to adopt General Motor's' production characteristics. This indicates that the somewhat counter-intuitive nature of our results, in terms of the single-product analysis, can be explained by the fact that the single-product analysis fails to take into account the way in which differences in product mix, in particular, can influence the overall degree of economies of scale.[34]

As indicated above, although there may be economies associated with the level of output, there may also be economies associated with the composition of output. Consequently, in assessing the relative efficiencies of firms it is desirable to estimate the degrees of economies of scope, which measure the effects of joint production upon costs. Following Baumol (1977) these economies can be measured by the following expression:

$$S_C = \frac{C(Y_T) + C(Y_{T-N}) - C(Y_N)}{C(Y_N)} \tag{10}$$

where T and T-N represent disjoint groups of the output set. Thus $C(Y_T)$ and $C(Y_{T-N})$ respectively represent the costs of producing output set (T) and output set (T-N) independently, while $C(Y_N)$ represents the costs of producing them jointly. Consequently S_C measures the percentage cost savings (increases) that are due to joint production and will be positive or negative depending upon whether economies or diseconomies of joint production exist.

Table 6a presents the estimated economies of scope that were calculated at the grand sample mean, each firm-specific mean, and the 1979 period. Given the severe imprecisions that can result from estimating these economies at zero production levels for particular outputs,[35] we used a range of small levels of production, as opposed to zero, in the calculations. The results indicate for all of the firms that there appear to be marked economies of joint production from combining the production of large cars with small cars and trucks and varying diseconomies from combining the production of trucks with the production of small and large cars. Interestingly, by the 1979 period it appears that at least Chrysler has achieved significant economies from the scope of its product lines.[36] It is also worth pointing out that by this period Chrysler, in contrast to Ford, would not gain any additional scope economies if it possessed General Motors' product mix (see Table 6b).[37]

In addition to examining the size-related economies at a single point in time, it is also useful to consider the degree of productivity growth in the industry. This can be measured by differentiating the estimated cost function with respect to time and estimating the following expression:

$$\frac{\partial C}{\partial T} = \delta_t + D_{TT}(T-\bar{T}) + \sum_i \sum_\ell D_{i\ell}(q_{i\ell}-\bar{q}_{i\ell}) + \sum_i D_{iT}(y_i-\bar{y}_i)$$
$$+ \sum_j D_{jT}(w_j-\bar{w}_j) \; . \qquad (11)$$

Using the estimated coefficients and firm-specific mean values of the variables, we can use equation (11) to simulate productivity changes for General Motors, Ford, and Chrysler through time. Note that since equation (11) represents the pure productivity effect, productivity growth can only be said to have occurred if $\partial C/\partial T$ is negative. The productivity estimates for the last ten years are presented in Table 7. The results indicate that Ford, and to some extent, General Motors, have enjoyed productivity growth for the majority of the past decade. In contrast, Chrysler has experienced fairly constant and large cost increases during this same period. These results are important since they suggest that even if Chrysler did not suffer a competitive disadvantage with respect to its recent scale of production, it would still be at a competitive disadvantage vis-a-vis Ford and General Motors because of its recent poor productivity.

V. Summary and Conclusions

From a methodological viewpoint, this paper has indicated that it is appropriate to analyze the structure of costs and technology in the automobile industry using the firm rather than the plant as the basic unit of observation. Thus by specifying and estimating a multiproduct cost function it has been possible to obtain considerable insight into the nature of productivity growth and of size-related economies, particularly those with respect to the scale and composition of output. Although this analysis has suffered from considerable data problems and its findings should be qualified accordingly, several interesting results emerge.

Perhaps the most striking finding was the wide variability in the measures of economies of scale and economies of scope at different levels of output. This indicates that the global cost surface is decidedly not convex, but exhibits variable regions of increasing and decreasing returns to scale and increasing and decreasing returns to multiple production. Thus broad generalizations based on specific production points are not appropriate.

Nevertheless, a relatively consistent pattern emerged in which Chrysler exhibited a lack of productivity growth, increasing returns from increased production and economies of joint production. In contrast, General Motors exhibited increasing returns to scale and some economies of multiple production, but improved productivity growth. The performance of Ford generally lay between that of General Motors and Chrysler, but on balance, Ford does not seem to suffer from the lack of productivity growth that appears to plague Chrysler.

Although it would be inappropriate to draw sweeping policy generalizations from this analysis, it is clear that it lends considerable quantitative insight into the source of Chrysler's current financial problems. While it appears that Chrysler has achieved some economies from its product mix, it is clear that Chrysler must significantly improve its productivity if it is to compete successfully in the domestic market. In contrast, our quantitative findings support the view that General Motors' U.S. operations are generally more efficient than those of its domestic competitors; apparently it has evolved into a domestic firm whose scale and product mix are relatively efficient at existing and increased output levels. This suggests, of course, that General Motors will play an increasingly dominant role in the domestic industry and that it should be able to compete in the U.S. effectively with its foreign competitors. Although the quantitative results for Ford give somewhat mixed signals, its strong productivity performance is encouraging; on balance, it should continue to be a relatively weak, but effective competitor on the domestic scene.

Of course, the preliminary nature of these findings should be stressed. Ideally, it would be useful to obtain comprehensive data on the costs of foreign operations; the capital stock utilized by each firm; and supplier relationships and the degree of vertical integration. In addition, it would be useful to incorporate into the analysis the effect upon costs of specific product or process innovations, market behavior, and governmental regulation concerning emissions, safety, and mileage. Therefore, these results should be viewed as a first step towards a fuller analysis of the costs of automobile production in a more realistic international context.

Consequently, in addition to continued work to improve upon the analysis of the costs of domestic producers, it would be highly desirable to extend this analysis to foreign producers. If it were possible to obtain comparable data for foreign firms, it would be possible to compare their technologies with that of domestic U.S. producers and analyze their relative efficiencies.

Finally, as indicated in the introduction, a full analysis of the eventual structure of the automobile industry requires an analysis of demand and market behavior as well as costs. Thus, this analysis should be viewed as a first step in a larger quantitative analysis of the industry. Nevertheless, the present results indicate that an econometric analysis of the costs of the automobile industry can yield considerable insight into the nature of its costs, its technology, and its productivity growth.

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Notes

1. In addition, Volkwagen has recently started domestic production. However, its scale of domestic operations is relatively small compared to the other domestic firms.

2. For a recent discussion of these and related issues see the Goldschmidt Report (1980).

3. In fact, Ford's domestic losses have been cushioned by profitable overseas operations. Thus, there is some question regarding the financial viability of Ford's domestic operations.

4. See, for example, Ben-Akiva (1977), Manski and Sherman (1980), Johnson (1978), Lave and Train (1977), and Wharton (1977).

5. See Abernathy and Clark (1980) and Leone (1980).

6. In addition to the possible bankruptcy of Chrysler and the effective take-over of American Motors by Renault, one should also cite the discussed mergers of Renault and Peugeot-Citroen. For a discussion of recent mergers in Europe see Jones (1980). More generally, see Cohen (1980) and Abernathy (1978).

7. For a discussion of the theoretical issues involved see Baumol (1977) and Baumol, Panzar, and Willig (1981). For empirical applications see Jara-Diaz and Winston (1981) and Wang Chiang and Friedlaender (1981).

8. This differentiation has existed, at least in the eyes of the consumer, if not in terms of the actual production process.

9. A recent example of this was the controversy that erupted when it was discovered that Chevrolet engines were incorporated into many makes and models of Oldsmobiles.

plants, they may have a fairly high degree of flexibility in utilization of their plant and equipment.

11. In recent years, however, this characterization of the industry appears to have broken down as imports have risen dramatically.

12. See, for example, Bain (1956), White (1971), Pratten (1971), Rhys (1972) and Toder et al. (1978).

13. See Spady and Friedlaender (1978) for a discussion of hedonic cost functions.

14. See McFadden (1978) for a discussion of the justification for introducing technological conditions into a cost function.

15. This variable captures purely time-related changes in costs and technology. See Stevenson (1980) for a discussion of this point.

16. In estimating cost functions empirically, it is generally important that no a priori restrictions be imposed concerning the structure of technology, particularly with respect to issues of homotheticity or elasticities of factor substitution. Since conventional functional forms such as the Cobb-Douglas or CES assume separable or homothetic technologies and impose constant elasticities of factor substitution, they may not be suitable. For a full discussion of these points see Hall (1973), and Berndt and Khaled (1979).

17. Given that we were unable to control for all of the factor prices in the specification (see below), we did not employ the usual practice (see Berndt et al. (1974)) of deleting one of the factor demand euqations in the estimation of the system.

18. Initially, efforts were made to include American Motors in the sample. However, the differences in the scale of operations between American Motors and the other three producers were sufficiently great, that the

approximation used to estimate the cost function did not appear to be valid in this case.

19. If, in fact, the underlying technology facing each firm were different, this could be statistically tested by the use of firm-specific dummy variables. When these were introduced, however, they proved to be statistically insignificant, indicating that there are no significant differences in the underlying technology facing the "Big Three" domestic auto producers.

20. To state the problem formally, production is nonjoint if the joint cost function $C = C(y_1,...,y_n;w)$ can be written as a nonjoint cost function, $C = \Sigma C_i(y_i,w)$, where y_i represents the output type i and w represents the vector of relevant factor prices. Note, however, that since $C = \Sigma C_i(y_i,w)$ is a restricted case of $C = C(y_1,...,y_n;w)$, no specification error results if a general joint cost function is estimated, when in fact production is nonjoint. With a nonjoint cost function, it is apparent that $\partial^2 C/\partial y_i \partial y_j = 0$. Hence by restricting the appropriate parameters of the joint cost function to be zero, one can statistically test whether the cost function is nonjoint (see Hall (1973)). Although a full joint cost function was estimated, the errors-in-variables problems created by the use of domestic factor prices were sufficiently great to make the results of this equation unreliable by usual statistical criteria. Hence we treated the assumption of nonjoint production for the time period covered by our sample as a maintained hypothesis and thus confined the cost analysis to domestic operations. Domestic costs were defined to include the

cost of goods sold, (including labor and materials), depreciation, selling and administration, amortization of special tools and equipment, interest, income taxes, maintenance and repair, other taxes, research and development, and an after-tax return to capital of 12 percent to reflect a normal rate of return. In addition to corporate annual reports, these data came from Moody's Industrial Manual.

21. It should be noted that this was the only breakdown of the costs of domestic and foreign operations that was readily available. Curiously, the financial reports (10-K's) of the companies do not include such a breakdown of costs.

22. Because these data were only available for 1979, we were forced to extrapolate these figures backward by assuming that Ford's foreign activity grew by 0.5 percent per year from 1955 to 1979, that General Motors' foreign activity grew by 0.5 percent per year between 1960 and 1979, and that Chrysler's foreign activity grew by 0.5 percent per year between 1955 and 1970, at which time it stabilized at its current levels. Although these assumptions are somewhat arbitrary, they do reflect the relative roles of foreign operations in the different companies.

23. These data came from Ward's Automotive Yearbook.

24. Since Ward's provides production statistics on the first five categories, the residual was obtained by subtracting these figures from total sales.

25. For an analysis of consumer valuation of automobile attributes see Griliches (1961).

26. These were calculated by taking a weighted average of the characteristics of the components of each group.

27. The utilization of steel in a typical automobile accounts for roughly two-thirds of the material inputs. In the course of carrying out the estimations we also used a constructed composite material index; however, the index did not lead to any improvement in the estimation results. Finally, it should be noted that since all of the factor prices did not appear in the cost system we did not impose the homogeneity condition in the estimations reported here.

28. In principle this variable could be measured as value-added as a percentage of sales. While this information is available on an industry basis, it is not readily available on a firm basis. Thus we could not incorporate it in our analysis.

29. Although firm-specific dummy variables can indicate that significant differences may exist in the structure of costs of each firm, they cannot indicate whether these differences are due to organizational structure or to basic technology. Thus their coefficients should be interpreted with considerable caution. They proved, however, to be statistically insignificant in the analysis, Cf. fn. 19.

30. This also follows since $F_{ji} = F_{ji}$ and we have argued that $\partial MC_i/\partial w_j = F_{ij} > 0$.

31. Output instruments were obtained for each firm by regressing each of their outputs on the following variables: their market share of that output in the previous year, the absolute level of that output in the previous year, disposable income per capita, GNP, prime interest rate, unemployment rate, total installment credit, and the retail gasoline price.

32. Note that the single-output measure of the elasticity of cost with respect to output is given by MC/AC and is greater or less than one as

decreasing or increasing returns to scale exist. A single-output measure of returns to scale is therefore given by the reciprocal of the cost elasticity (that is, $S = AC/MC = \frac{C/Y}{\partial C/\partial Y}$). Equation (9) is a multi-output generalization of the single-output measure of scale economies and is consequently $\gtrless 1$ as production is subject to increasing, constant, or decreasing returns to scale.

33. The results were virtually unaffected when the calculations were carried out using GM's product mix alone, or combinations of the product mix and either the factor prices or hedonic attributes.

34. Given these dramatic differences in measured scale economies, it would be tempting to assert that the firms must face different technologies. However, a statistical test did not support this hypothesis, Cf. fn. 19.

35. In particular, marginal and total costs can actually become negative.

36. This conclusion should admittedly be qualified as the approximation upon which the calculations are based may not be particularly accurate given Chrysler's relatively low level of production during this period.

37. As a somewhat related point, it is interesting to note that the industry would not become more efficient, from a cost perspective, if it were completely monopolized. Specifically, we find at the mean output that $\sum_i C_i(Y) = 38021$(million) $> C(\sum_i Y_i) = 38810$(million), while in 1979 $\sum_i C_i(Y) = 96557$(million) $> C(\sum_i Y_i) = 127779$(million). In short, the industry cost function does not exhibit subadditivity, which is a necessary and sufficient condition for the presence of natural monopoly (see Baumol (1977)).

Table 1. Notation of Variables Used in Estimation

Notation	Variable
C	total cost of domestic production per year (in million dollars)
y_1	small car production per year (subcompact and compact)
y_2	large car production per year (full-size and luxury)
y_3	truck production per year
q_{11}	wheel base of small car (in inches)
q_{12}	weight of small car (in pounds)
q_{13}	cylinder capacity of small car (in cubic inches)
q_{21}	wheelbase of large car (in inches)
q_{22}	weight of large car (in pounds)
q_{23}	cylinder capacity of large car (in cubic inches)
q_{31}	weight of truck (in pounds)
w_1	labor price (in dollars per hour)
w_2	capital price (in percent per dollar per year)
w_3	materials price (in dollars per ton)
T	dummy variable for time

Table 2. Distribution of the Variables Used in the Sample

	INDUSTRY		GENERAL MOTORS		FORD		CHRYSLER	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Total Cost ($ million)								
Domestic	12818.0	10604.7	21156.9	12549.7	10836.6	7454.8	6462.0	3883.7
Output (unit)								
small car	533,315	422,032	654,442	527,142	597,108	404,658	348,395	228,927
large car	1,898,603	1,185,650	3,388,474	679,305	1,506,827	260,869	800,507	277,158
truck	525,160	370,294	764,650	384,667	607,742	284,319	203,089	138,102
Factor Input Prices								
labor ($/hr)	6.91	3.83	7.14	4.05	6.66	3.73	6.94	3.83
capital (%)	12.64	2.22	12.53	1.85	12.53	1.94	12.86	2.22
material ($/ton)	7.68	4.33	7.68	4.33	7.68	4.33	7.68	4.33
Hedonic Quality								
small car: wheelbase (in)	106.25	2.90	105.88	2.11	104.97	3.60	109.11	1.85
weight (lb)	2875.96	296.54	2896.19	293.40	2781.41	313.53	3000.0	265.14
cylinder (in^3)	222.26	48.03	234.65	52.50	210.22	56.46	219.62	31.82
large car: wheelbase (in)	118.84	1.68	118.99	2.18	118.31	1.16	119.21	1.48
weight (lb)	3802.07	321.6	3830.76	288.3	3778.96	388.8	3724.11	285.2
cylinder (in^3)	337.77	30.7	341.14	32.7	331.81	35.9	334.74	22.4
truck weight (lb)	7747.26	1132.6	7170.82	453.8	7972.37	722.7	6916.69	175.4

Table 3

Domestic Cost System

VARIABLE	COEFFICIENT	STANDARD ERROR
constant	12845.1	603.05
y_1 (small car)	0.002264	0.002058
y_2 (large car)	0.004282	0.000620
y_3 (truck)	0.005499	0.003055
y_1y_1	-1.3×10^{-9}	1.3×10^{-8}
y_1y_2	-2.9×10^{-9}	2.2×10^{-9}
y_1y_3	2.1×10^{-8}	1.1×10^{-8}
y_2y_2	-3.8×10^{-10}	9.5×10^{-10}
y_2y_3	-6.6×10^{-10}	2.2×10^{-9}
y_3y_3	-7.1×10^{-10}	1.01×10^{-9}
w_1 (labor)	541.1	9.15
w_2 (capital)	146.0	3.28
w_3 (material)	878.2	13.96
w_1w_1	-33.0	7.67
w_1w_2	-13.51	2.58
w_1w_3	26.43	6.20
w_2w_2	-15.30	1.80
w_2w_3	-5.36	2.21
w_3w_3	-48.00	6.95
w_1y_1	-5.16×10^{-5}	6.06×10^{-5}
w_1y_2	27.4×10^{-5}	1.35×10^{-5}
w_1y_3	-8.83×10^{-5}	6.77×10^{-5}
w_2y_1	5.37×10^{-5}	2.18×10^{-5}
w_2y_2	8.21×10^{-5}	4.99×10^{-6}
w_2y_3	2.64×10^{-5}	2.52×10^{-5}
w_3y_1	4.23×10^{-5}	9.21×10^{-5}
w_3y_2	25.8×10^{-5}	2.04×10^{-5}
w_3y_3	17.8×10^{-5}	10.2×10^{-5}

Table 3, continued

VARIABLE	COEFFICIENT	STANDARD ERROR
T (time)	-140.8	140.8
Ty_1	-0.000348	0.00075
Ty_2	0.000258	0.00019
Ty_3	-0.00152	0.000769
Tw_1	15.475	3.66
Tw_2	1.1293	1.34
Tw_3	21.19	5.336
TT	59.76	41.39
q_{11} (wheelbase small car)	-24.713	76.141
q_{12} (weight small car)	-0.4352	2.45
q_{13} (cylinder capacity, small car)	-8.24	12.37
q_{21} (wheelbase, large car)	520.235	286.42
q_{22} (weight large car)	0.96	2.26
q_{23} (cylinder capacity, large car)	12.67	13.52
q_{31} (weight truck)	-0.0344	0.3794
Tq_{11}	-15.31	8.65
Tq_{12}	0.4544	0.466
Tq_{13}	-2.1979	3.29
Tq_{21}	18.747	36.159
Tq_{22}	0.0625	0.2577
Tq_{23}	2.1676	2.0056
Tq_{31}	-0.0124	0.0363

	R^2	$\bar{R}^2$
Cost Equation	0.98	0.94

Table 4

Elasticities of Substitution Evaluated at Grand Sample Mean

	Labor	Capital	Materials
Labor	-1.49	2.19	0.71
Capital		-9.04	-0.54
Materials			-0.80

Table 5a

Global Economies of Scale by Firm

	Sample Mean	1979
Industry's typical firm	1.05	1.23
General Motors	1.23	1.10
Ford	0.88	0.79
Chrysler	1.16	7.44

Table 5b

Multiproduct Economies of Scale

	Sample Mean	1979
Ford: with General Motors' product mix, factor prices, and hedonic attributes	1.17	1.76
Chrysler: with General Motors' product mix, factor prices, and hedonic attributes	1.24	4.40

Table 6a

Economies of Scope

SAMPLE MEAN

Output Level:	10 percent	1 percent	0.1 percent
INDUSTRY			
{small car} + {large car & truck}	-0.10	-0.14	-0.15
{large car} + {small car & truck}	0.27	0.35	0.36
{truck} + {small car & large car}	-0.23	-0.32	-0.32
GENERAL MOTORS			
{small car} + {large car & truck}	-0.08	-0.14	-0.14
{large car} + {small car & truck}	0.37	0.45	0.46
{truck} + {small car & large car}	-0.25	-0.36	-0.38
FORD			
{small car} + {large car & truck}	-0.29	-0.35	-0.36
{large car} + {small car & truck}	0.22	0.33	0.34
{truck} + {small car & large car}	-0.41	-0.52	-0.54
CHRYSLER			
{small car} + {large car & truck}	0.06	0.06	0.06
{large car} + {small car & truck}	0.27	0.32	0.33
{truck} + {small car & large car}	-0.03	-0.06	-0.07

Table 6a, continued

1979

Output Level:	10 percent	1 percent	0.1 percent
INDUSTRY			
{small car} + {large car & truck}	0.05	0.02	0.02
{large car} + {small car & truck}	0.59	0.73	0.75
{truck} + {small car & large car}	-0.08	-0.14	-0.15
GENERAL MOTORS			
{small car} + {large car & truck}	-0.10	-0.15	-0.15
{large car} + {small car & truck}	0.53	0.68	0.70
{truck} + {small car & large car}	-0.31	-0.42	-0.43
FORD			
{small car} + {large car & truck}	-0.41	-0.50	-0.51
{large car} + {small car & truck}	0.52	0.77	0.80
{truck} + {small car & large car}	-0.54	-0.66	-0.68
CHRYSLER			
{small car} + {large car & truck}	0.82	0.82	0.82
{large car} + {small car & truck}	1.01	1.06	1.06
{truck} + {small car & large car}	0.79	0.78	0.78

Table 6b

Economies of Scope (1-percent output level)

	With General Motors' Product Mix, Factor Prices, and Hedonic Attributes
Ford (sample mean)	
{small car} + {large car & truck}	.01
{large car} + {small car & truck}	.27
{truck} + {small car & large car}	-.09
Ford (1979)	
{small car} + {large car & truck}	.33
{large car} + {small car & truck}	.67
{truck} + {small car & large car}	.21
Chrysler (sample mean)	
{small car} + {large car & truck}	.13
{large car} + {small car & truck}	.25
{truck} + {small car & large car}	.08
Chrysler (1979)	
{small car} + {large car & truck}	.71
{large car} + {small car & truck}	.81
{truck} + {small car & large car}	.74

Table 7

Productivity Change for General Motors, Ford, and Chrysler, 1969-1979

GENERAL MOTORS

Year	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial C}{\partial T}$ (percent)
1979	-272.771	-0.53
1978	-690.627	-1.40
1977	-447.011	-1.03
1976	2.6373	0.007
1975	-241.303	-0.84
1974	814.777	3.14
1973	13.4968	0.05
1972	-239.038	-0.97
1971	-137.479	-0.60
1970	202.399	1.26
1969	147.01	0.73

FORD

Year	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial C}{\partial T}$ (percent)
1979	-433.09	-1.54
1978	-643.88	-2.35
1977	-308.15	-1.27
1976	-38.78	-0.21
1975	-6.78	-0.04
1974	-149.53	-0.93
1973	-214.75	-1.40
1972	-140.50	-1.03
1971	-101.18	-0.90
1970	-363.12	-3.54
1969	-487.59	-4.82

Table 7, continued

CHRYSLER

Year	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial T}{\partial T}$ (percent)
1979	904.22	7.81
1978	579.41	4.69
1977	595.34	4.05
1976	430.97	3.21
1975	611.43	5.88
1974	268.72	2.76
1973	245.10	2.41
1972	226.93	2.68
1971	350.89	4.90
1970	366.32	5.70
1969	459.46	7.12

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