Costs, technology, and productivity in the U.S. automobile industry

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This article 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 so advantageous as General Motors', its recent productivity growth suggests that it can remain an effective competitor in the domestic automotive market.

1. 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-hundred 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 or materials suppliers, 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 has the Chrysler Corporation been perilously close to bankruptcy, but Ford and General Motors have sustained unprece-

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[1] In addition, Volkswagen has recently started domestic production. However, its scale of domestic operations is relatively small compared with the other domestic firms.

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

dented losses in recent years.[3] Moreover, Renault of France has recently bought a major interest in American Motors, making it effectively a subsidiary of the French company. In addition, imports (particularly Japanese) have managed to achieve substantial penetration of the domestic market (approaching 30%), apparently indicating that the domestic producers have not been able to respond effectively to recent changes in consumer tastes.[4] 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. Although considerable empirical work has already been undertaken with respect to the demand for automobiles (Ben-Akiva, 1977; Manski and Sherman, 1980; Johnson, 1978; Lave and Train, 1977; Wharton, 1977) and comparative labor costs and productivity (Abernathy and Clark, 1980; Leone *et al.*, 1980), there has been relatively little empirical work on the underlying technology of the automobile industry. Without 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.[5] 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 output 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.[6] Despite formidable data problems, this article 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. It is hoped that the approach taken here can be extended to analyze the behavior of foreign producers.

The article proceeds as follows. Section 2 presents an overview of the institutional organization and characteristics of the automobile industry. Section 3 develops the an-

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[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] It appears that the penetration of foreign producers has peaked, since in the last few years most foreign producers' shares have either stabilized or, as in the case of Volkswagen, declined.

[5] In addition to the possible bankruptcy of Chrysler and the effective takeover 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).

[6] For a discussion of the theoretical issues involved, see Baumol (1977) and Baumol, Panzar, and Willig (1982). For empirical applications, see Winston, Jara-Diaz, and Kravtin (1982), Wang Chiang and Friedlaender (1981), and Fuss and Waverman (1981).

alytical framework that is used to guide the empirical analysis and describes the data base. Section 4 discusses the empirical results, and Section 5 presents a summary and the policy implications of the analysis.

2. 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. Although 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 stresses 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.[7] 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).

Although 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 among 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 model (e.g., Malibu). Thus, 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.[8] 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 or materials inputs.

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

[8] 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.

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 design. 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.[9]

Finally, it is important to note that the domestic automobile industry before 1979 or 1980 could be characterized as a tight oligopoly, with General Motors recognized as the dominant firm. Although 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.[10] 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 variables in the cost function. It is also recognized, however, that since the bulk of the remaining outputs must be allocated between Ford and Chrysler, 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 article, we therefore argue that the outputs of the larger firm, Ford, should also be treated an endogenous, while those of Chrysler should be treated as exogenous.[11]

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 different 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.

3. Conceptual framework, data, and variables

■ **Conceptual framework.** Although there have been many studies analyzing the costs of automobile production (Bain, 1956; White, 1971; Pratten, 1971; Rhys, 1972; Toder *et al.*, 1978), 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, automobile manufacturers produce a wide variety of outputs and since there

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[9] To the extent, however, that firms are able to shut down obsolete plants, they may have a fairly high degree of flexibility in utilization of their plant and equipment.

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

[11] In other words, given the total market demand for vehicles, Chrysler's output is treated as an exogenously determined residual after Ford's and General Motors' output levels have been determined. To be sure, this characterization may not be realistic in the face of significant market penetration by foreign producers. This phenomenon relates, however, to only a small time period covered by our sample. As an empirical issue, we test for exogeneity in the context of our econometric specification. (See footnote 32.)

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 economies that may be related to the size of the firm and its composition of output as well as to 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:[12]

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

where

C = total costs
Ψ_i = generic level of the ith output
Y_i = physical level of the ith output
q_i = qualities associated with the ith output
w = vector of factor prices
t = vector of technological conditions[13]
T = time variable[14].

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).[15] In this analysis we utilize a quadratic approximation, which represents a second-order Taylor approximation around the mean.[16] We thus write the cost function as:

$$\begin{aligned} C = {} & \alpha_0 + \sum_i \alpha_i(\phi_i - \bar{\phi}_i) + \sum_j \beta_j(w_j - \bar{w}_j) + \sum_h \gamma_h(t_h - \bar{t}_h) + \delta_T(T - \bar{T}) \\ & + \tfrac{1}{2}\Big[\sum_i \sum_m A_{im}(\phi_i - \bar{\phi}_i)(\phi_m - \bar{\phi}_m) + \sum_j \sum_n B_{jn}(w_j - \bar{w}_j)(w_n - \bar{w}_n) \\ & + \sum_h \sum_l C_{hl}(t_h - \bar{t}_h)(t_l - \bar{t}_l) + D_{TT}(T - T)^2\Big] + \sum_i \sum_j E_{ij}(\phi_i - \bar{\phi}_i)(w_j - \bar{w}_j) \\ & + \sum_i \sum_h F_{ih}(\phi_i - \bar{\phi}_i)(t_h - \bar{t}_h) + \sum_i G_{iT}(\phi_i - \bar{\phi}_i)(T - \bar{T}) + \sum_j \sum_h H_{jh}(w_j - \bar{w}_j)(t_h - \bar{t}_h) \\ & + \sum_j J_{jT}(w_j - \bar{w}_j)(T - \bar{T}) + \sum_h K_{hT}(t_h - \bar{t}_h)(T - \bar{T}) + \epsilon, \end{aligned} \tag{2}$$

[12] See Spady and Friedlaender (1978) for a discussion of hedonic cost functions.

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

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

[15] 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).

[16] Baumol, Panzar, and Willig (1982) have argued that the quadratic approximation is particularly attractive to use in multiple-output cost functions since it permits an easy analysis of marginal costs and scale and scope economies. Although the use of the quadratic approximation has been criticized for its inability to impose the homogeneity condition needed for cost minimization (Caves, Christensen, and Tretheway, 1980), Berndt, Fuss, and Waverman (1979) have developed procedures to deal with this problem. In any event, this problem is not significant for our analysis, since data limitations prevent us from controlling for all of our factor prices in the analysis. (See footnote 28.)

Although the translog approximation is also frequently used in estimating cost functions, the existence of a large number of zero outputs for small cars in the early portion of our sample would clearly have presented substantial problems in using this functional form. It is possible to use a Box-Cox transformation in a translog specification to circumvent the problem of zero values, but the limited number of observations in our sample and the increase in the number of parameters to be estimated that is involved in such a transformation precluded its use.

where

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

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

$$C_{hl} = C_{lh} \; \forall h, l$$

and ϵ 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

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

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 jth factor

$$X_j = \frac{\partial C}{\partial w_j} = \beta_j + \sum_n B_{jn}(w_n - \bar{w}_n)$$
$$+ \sum_i E_{ij}(\phi_i - \bar{\phi}_i) + \sum_h H_{jh}(t_h - \bar{t}_h) + J_{jT}(T - \bar{T}) + \epsilon_j, \tag{4}$$

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]

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 2. Thus we now turn to a discussion of our data base and then present the specification used in the empirical analysis.

□ **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 differences in organizational structure, their production technologies are sufficiently similar for us to analyze them as if they shared a common technology.[19]

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

[18] Initially, efforts were made to include American Motors in the sample. But 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. More specifically, it is highly likely that American Motors' technology is different from the technology employed by the Big Three because it is less vertically integrated. Further, given its smaller scale of operations and lack of integration, American Motors produces a much smaller set of makes and models than the Big Three producers.

[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, thereby indicating that there are no significant differences in the underlying technology facing the "Big Three" domestic auto producers. Unfortunately, a Chow test or a test which utilized dummy variables that interacted with specific variables, such as factor prices or outputs, could not be employed because of a lack of degrees of freedom. Nonetheless, our finding regarding a common technology among the Big Three producers is consistent with conventional wisdom regarding the industry. For instance, Edwards (1965) points out that there has been a significant exchange of production technology within the domestic industry. In addition, White (1971) argues that little, if any, of the technology is secret, since there are no key patents controlling the basic manufacturing processes in the industry.

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. Although 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 come from the firms' annual reports and hence include costs of foreign and nonautomotive operations. But, the available data on factor prices reflect 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] Finally, it should be noted that the domestic expenditures on each factor were derived from the firms' annual reports.

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 nonau-

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[20] To state the problem formally, production is nonjoint if the joint cost function $C = C(y_1, \ldots, y_n; w)$ 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 $C = C(y_1, \ldots, y_n; w)$, 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 (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% 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. Following Young and Hood's (1977) description of the Big Three producers' investment pattern in Europe, we assumed that Ford's foreign activity grew by .5% per year from 1955 to 1979, that General Motors' foreign activity grew by .5% per year between 1960 and 1979, and that Chrysler's foreign activity grew by .5% per year between 1955 and 1970, at which time it stabilized at its current levels. Although these assumptions are based on the Big Three producers' European activity, it should be noted that this activity constitutes a very large proportion (70%–80%) of their overseas production (Young and Hood, 1977). As an econometric point, it is worth pointing out that any imprecisions that might result from the procedure described above would lead to a measurement error in the dependent variable. It appears that such an error would not be systematically related to any of the explanatory variables, so that it is likely that the parameter estimates would remain consistent.

[23] These data came from *Ward's Automotive Yearbook.*

tomotive production.[24] But when the estimation was undertaken, it was found that the range of output was sufficiently variable that the approximation of the cost function around the sample mean deteriorated. In particular, we were unable to obtain marginal cost estimates that were within an acceptable range of reasonableness. Hence further aggregation was used, and the following three output variables were included 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 only the following three factors in the analysis: labor, capital, and materials. As indicated above, it would have been desirable to treat capital as a fixed factor (incorporating different vintages), but 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 the price of its capital. 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.[27] 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.[28]

The technological variables used in the cost function should include not only 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.[29] Since data reflecting interfirm organizational differences are not readily available, a reasonable proxy is the use of simple firm-specific dummy variables.[30]

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[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 characteristics were calculated as a weighted average for each output group.

[27] See Brealey and Meyers (1981) for a discussion and justification of this procedure.

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

[29] In principle, this variable could be measured as value-added as a percentage of sales. Although 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.

[30] 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. footnote 19). In a recent article, Monteverde and Teece (1982) used a limited dependent variable model to analyze the likelihood of vertical integration in the production of specific automobile components. Unfortunately, their analysis does not yield a measure of vertical integration that we could use, because they considered individual components instead of the overall production of vehicles. Moreover, since their measure of vertical integration is confined to dummy variables, it does not seem to differ substantially from the firm-specific dummy variables we used in this article.

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 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.

□ **Final specification.** Initial attempts were made to estimate the cost and factor demand equations given in equations (2)–(4) with the full complement of technological variables and a full range of outputs. But, 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, in the final estimation we 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 forms:

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

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

where $A_{im} = A_{mi}\ \forall i, m$; $B_{jn} = B_{nj}\ \forall n, j$; and ϵ and ϵ_j represent the error terms for the cost equation and the jth 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

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

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

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

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 jth 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 $\partial X_j/\partial w_n$ represents the change in demand for factor j with respect to the price of factor n, 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.[31] Finally, the change in the demand for the jth 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 jth factor's augmented technical change.

Since the interaction terms between quality attributes and the other variables have been restricted to zero, the γ_{il} coefficients reflect the changes 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 with production, they could be positive or negative. Finally, the D_{ilT} variables represent the changes in these costs with respect to time and can also be positive or negative, depending on the nature of technical change.

4. Empirical results

■ As pointed out in Section 2, General Motors' and Ford's outputs cannot be assumed to be exogenous. Consequently, an instrument was constructed for each of their outputs.[32]

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

[32] Instruments were obtained for each firm's outputs by regressing each of the outputs on the following variables: the firm's 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. The specification that is obtained by this procedure is basically an aggregate demand model for each type of output (see Wharton (1977) for a similar demand specification). It should be noted that the specification described here had the best predictive power of the specifications that were considered. Finally, the theoretical assertion that Chrysler's output should be treated as exogenous was tested empirically. Following the idea developed in Hausman's (1978) specification test, we used the sum of squared residuals from the specification which instrumented all of the outputs and the sum of squared residuals from our specification where Chrysler's output was treated as exogenous. The F-test statistic was .641 while the 5% critical value is 3.47; hence, for our specification we could not reject exogeneity at the 5% level.

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	3000.00	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	321.60	3830.76	288.30	3778.96	388.80	3724.11	285.20
cylinder (in.^{3})	337.77	30.70	341.14	32.70	331.81	35.90	334.74	22.40
truck:								
weight (lb.)	7747.26	1132.60	7170.82	453.80	7972.37	722.70	6916.69	175.40

TABLE 3 **Domestic Cost System**

Variable	Coefficient	Standard Error
constant	12845.1	603.05
y_1 (small car)	.002264	.002058
y_2 (large car)	.004282	.000620
y_3 (truck)	.005499	.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^{-9}	1.01×10^{-8}
w_1 (labor)	541.1	9.15
w_2 (capital)	146.5	3.28
w_3 (material)	878.2	13.96
w_1w_1	−33.9	7.88
w_1w_2	13.51	2.58
w_1w_3	26.43	6.20
w_2w_2	−15.30	1.80
w_3w_3	−48.29	6.99
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}
T (time)	−140.8	140.8
Ty_1	−.000348	.00075
Ty_2	.000258	.00019
Ty_3	−.00152	.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)	−.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)	.96	2.26
q_{23} (cylinder capacity, large car)	12.67	13.52
q_{31} (weight, truck)	−.0344	.3794
Tq_{11}	−15.31	8.65
Tq_{12}	.4544	.466
Tq_{13}	−2.1979	3.29
Tq_{21}	18.747	36.159
Tq_{22}	.0625	.2577
Tq_{23}	2.1676	2.0056
Tq_{31}	−.0124	.0363

	R^2	$\bar{R}^2$
Cost Equation	.98	.94
Labor Equation	.93	.92
Capital Equation	.95	.94
Material Equation	.90	.90

Then, using the data base described in Section 3, we estimated the cost and factor demand equations with Zellner's seemingly unrelated regression procedure.

The parameter estimates pertaining to the domestic cost system are presented in Table 3.[33] 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.[34] 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 and, given that each coefficient is at least as large as its standard error, indicate reasonable reliability.

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.[35] The elasticity of substitution between two inputs, r and s, is equal to

$$\delta_{rs} = \frac{d \ln \left(\frac{X_r}{X_s}\right)}{d \ln \left(\frac{w_r}{w_s}\right)} = \frac{CC_{rs}}{C_r C_s}, \tag{8}$$

where the subscripts pertaining to the total cost, C, denote partial derivatives. The estimates of the elasticities of substitution and their standard errors (at the point of approximation) are presented in Table 4. The results indicate that both labor and capital and

TABLE 4 Elasticities of Substitution Evaluated at Grand Sample Mean*

	Labor	Capital	Materials
Labor	−1.49	2.19	0.71
	(.35)	(.43)	(.169)
Capital		−9.04	−0.54
		(1.24)	(.222)
Materials			−0.80
			(.127)

* Standard errors in parentheses.

[33] Although we report on the significance of various alternative specifications throughout the article, it is useful to summarize these results briefly. First, the most significant improvements in initial specifications that led to the current model included using instruments for the output variables and using a more precise capital price, which was based on the capital-asset pricing model, instead of a simple weighted average of the cost of long-term debt. The first change led to more reasonable estimates of scope economies (estimates that were based on a specification where the outputs were not instrumented were often significantly greater than one), while the second change led to more reasonable estimates of marginal costs and factor elasticities. In addition to these improvements, a number of alternative specifications were estimated, which included a range of technological variables, a dummy variable to capture technological differences among firms, a constructed composite materials index, and further disaggregation of output. Unfortunately, all of these changes proved unsuccessful, since the estimated parameters associated with these variables were highly insignificant. In addition, in some cases different specifications yielded somewhat less reasonable marginal cost estimates or less precise estimates of factor elasticities (particularly with respect to capital and materials).

[34] For the most part, the coefficients with regard to the hedonic qualities are also statistically unreliable.

[35] Standard errors are provided for estimates that correspond to the industry's sample mean. Unfortunately, calculation of the standard errors at points other than the sample mean (including for the typical firm in the 1979 period) imposes excessive computational requirements, since the variances and covariances of the 49 parameters that were estimated need to be included in the calculations. When the standard errors are evaluated at the sample mean, the number of parameters that are needed in the calculations falls significantly.

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. That is, although *a priori* it seemed that it would be desirable to derive a long-run cost function from an estimated short-run cost function that included a fixed capital stock as an argument, our empirical results suggest that this procedure is not necessary.[36] To be sure, the demand elasticity for capital is rather large by traditional standards; nonetheless the careful construction of the underlying capital price and the statistical precision of the elasticity estimate (as indicated by its relatively low standard error) suggest that the implications that we draw from the estimate are very likely to be valid.

The estimated coefficients can also be used to calculate the multiproduct 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:

$$S_m = \frac{C(Y)}{\sum_i Y_i \frac{\partial C}{\partial Y_i}}. \tag{9}$$

This will be greater or less than one in economies or diseconomies of scale exist; a value of one represents constant returns to scale.[37]

Table 5a presents the estimated returns to scale for a "typical" firm producing at the sample mean and in the most recent time-period in our sample, 1979, and for each of

TABLE 5

a. Global Economies of Scale by Firm*

	Sample Mean	1979
Industry's typical firm	1.05 (.09)	1.23
General Motors	1.23	1.10
Ford	0.88	0.79
Chrysler	1.16	7.44

* Standard error in parentheses.

b. 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

[36] It should be noted that this conclusion is only suggestive, since we treat the assumption that firms are in long-run equilibrium as a maintained hypothesis in our empirical analysis.

[37] 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 $\left(\text{that is, } S = AC/MC = \frac{C/Y}{\partial C/\partial Y}\right)$. Equation (9) is a multiproduct generalization of the single-output measure of scale economies and is consequently $\gtreqless 1$ as production is subject to increasing, constant, or decreasing returns to scale.

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 consider the 1979 period. The results for the 1979 period are striking, however, 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.[38]

The difference in the estimated scale economies among the firms in the sample is striking and also somewhat counterintuitive in terms of the conventional 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.[39]

The reasonableness of this result can be understood by reestimating 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.[40] As can be seen in Table 5b, both Ford and Chrysler would exhibit economies of scale if they were able to adopt General Motors' production characteristics. This indicates that the somewhat counterintuitive 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 can influence the overall degree of economies of scale.[41]

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), we can measure these economies by the following definition:

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

where T and $N - T$ represent disjoint groups of the output set and $T \cup (N - T) = N$. Thus $C(Y_T)$ and $C(Y_{N-T})$ respectively represent the costs of producing output set (T) and output set ($N - T$) independently, while $C(Y_N)$ represents the cost 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, at each firm-specific mean, and for the 1979 period. Since marginal and total costs can actually become negative when these economies are estimated at zero

[38] The accuracy of our approximation for specific time periods is not so great as at the sample mean. With this in mind, one should reasonably consider the 1979 scale estimate for Chrysler in terms of its qualitative significance.

[39] As a technical point, it can be shown for our specification that ray average costs are U-shaped (and not declining everywhere), thus not precluding the results we actually obtain.

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

[41] Given these dramatic differences in measured scale economies, it would be tempting to assert that the firms must face different technologies. But a statistical test did not support this hypothesis (cf. footnote 19).

TABLE 6 Economies of Scope

a.

Sample Mean Output Level:	10%	1%	.1%
Industry			
{small car} + {large car & truck}	−.10	−.14	−.15
{large car} + {small car & truck}	.27	.35	.36
{truck} + {small car & large car}	−.23	−.32	−.32
General Motors			
{small car} + {large car & truck}	−.08	−.14	−.14
{large car} + {small car & truck}	.37	.45	.46
{truck} + {small car & large car}	−.25	−.36	−.38
Ford			
{small car} + {large car & truck}	−.29	−.35	−.36
{large car} + {small car & truck}	.22	.33	.34
{truck} + {small car & large car}	−.41	−.52	−.54
Chrysler			
{small car} + {large car & truck}	.06	.06	.06
{large car} + {small car & truck}	.27	.32	.33
{truck} + {small car & large car}	−.03	−.06	−.07

1979 Output Level:	10%	1%	.1%
Industry			
{small car} + {large car & truck}	.05	.02	.02
{large car} + {small car & truck}	.59	.73	.75
{truck} + {small car & large car}	−.08	−.14	−.15
General Motors			
{small car} + {large car & truck}	−.10	−.15	−.15
{large car} + {small car & truck}	.53	.68	.70
{truck} + {small car & large car}	−.31	−.42	−.43
Ford			
{small car} + {large car & truck}	−.41	−.50	−.51
{large car} + {small car & truck}	.52	.77	.80
{truck} + {small car & large car}	−.54	−.66	−.68
Chrysler			
{small car} + {large car & truck}	.82	.82	.82
{large car} + {small car & truck}	1.01	1.06	1.06
{truck} + {small car & large car}	.79	.78	.78

production levels for particular outputs,[42] we used a range of small levels of production, as opposed to zero, in the calculations. The results indicate that for all of the firms there appear to be marked economies of joint production from combining the production of large cars with small cars and trucks, varying diseconomies from combining the produc-

[42] This result is only a statistical possibility that generally arises from the nature of the approximation. In particular, when one estimates a second-order approximation around the mean, the resulting equation is generally robust about the mean. As one uses values of the variables that deviate significantly from the mean, however, the approximation deteriorates, and counterintuitive results may occur. In the case of measurements of scope economies, where output levels are set to zero, the approximation often deteriorates to such a degree that negative estimates of marginal costs are obtained. Hence, observed negative marginal costs are a statistical artifact. Consequently, one would not expect them to occur either in theory or in practice.

TABLE 6 (*Continued*)

b.

	1% 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

tion of trucks with the production of small and large cars, and varying economies and diseconomies from combining the production of small cars with the production of large cars and trucks. It is interesting that by the 1979 period, at least Chrysler seems to have achieved significant economies from the scope of its product lines.[43] 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).[44]

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 calculating the following expression:

$$\frac{\partial C}{\partial T} = \delta_t + D_{TT}(T - \bar{T}) + \sum_i \sum_l D_{il}(q_{il} - \bar{q}_{il}) + \sum_i D_{iT}(y_i - \bar{y}_i) + \sum D_{jT}(w_j - \bar{w}_j). \quad (11)$$

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 be said to have occurred only 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,

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

[44] 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 (Baumol, 1977).

TABLE 7 Productivity Change for General Motors, Ford, and Chrysler, 1969–1979

	General Motors		Ford		Chrysler	
Year	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial C}{\partial T}$ (%)	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial C}{\partial T}$ (%)	$\frac{\partial C}{\partial T}$ (mil.)	$\frac{\partial C}{\partial T}$ (%)
1979	−272.771	−.53	−433.09	−1.54	904.22	7.81
1978	−690.627	−1.40	−643.88	−2.35	579.41	4.69
1977	−447.011	−1.03	−308.15	−1.27	595.34	4.05
1976	2.6373	.007	−38.78	−.21	430.97	3.21
1975	−241.303	−.84	−6.78	−.04	611.43	5.88
1974	814.777	3.14	−149.53	−.93	268.72	2.76
1973	13.4968	.05	−214.75	−1.40	245.10	2.41
1972	−239.038	−.97	−140.50	−1.03	226.93	2.68
1971	−137.479	−.60	−101.18	−.90	350.89	4.90
1970	202.399	1.26	−363.12	−3.54	366.32	5.70
1969	147.01	.73	−487.59	−4.82	459.46	7.12

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-à-vis Ford and General Motors because of its recent poor productivity.

5. Summary and conclusions

■ From a methodological viewpoint, this article has indicated that it is appropriate to analyze the structure of costs and technology in the automobile industry by 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 was generally 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. Although 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 that General Motors will play an increasingly dominant role in the domestic industry and that in the United States it should be able to compete 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 toward 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 those of domestic U.S. producers and to 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 of 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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