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DEPARTURES FROM MARGINAL-COST PRICING IN THE AMERICAN AUTOMOBILE INDUSTRY

Estimates for 1977–1978*

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How are prices set in the American automobile oligopoly? This paper seeks empirical estimates of the extent of departure from marginal-cost pricing and of the effects of foreign competition. The model estimated has product differentiation, multiproduct firms, and heterogeneity in consumer tastes. The estimation presumes that product type (proxied by engineering specifications) is exogenous to the price/quantity market equilibrium. Cross-section results for the 1977 and 1978 model years yield price–cost margins around 10%. Import competition has the effect of lowering equilibrium margins for compact and subcompact models.

1. Introduction

The American automobile market is characterized by oligopoly with product differentiation. This paper explores empirically the extent to which prices depart from marginal costs. The estimation problem is approached by taking product type (proxied by engineering specifications) to be exogenous to the price/quantity market equilibrium. The model is estimated on a cross-section of automobile products for the 1977 and 1978 model years.

The institutional facts of the auto industry suggest taking product type to be exogenous to the price/quantity market equilibrium. Because of the time and expense involved in changing an automobile's design, manufacturers do not usually react to one anothers' prices with model changes during the model year. The implicit auto market equilibrium has two distinct stages. In advance of the model year, firms select the product types they will market. During the model year, they set prices, unable to alter their product types.[1] This paper estimates only the second half of the overall equilibrium; the relationship between product type and market prices and quantities.

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[1]Existence of such a two-stage equilibrium was shown in Bresnahan (1980).

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It is a question of method that leads to estimation of the equilibrium mapping from product types to prices and quantities. Only this procedure can estimate the parameters of the underlying cost and demand systems. By solving explicitly for market equilibrium, all restrictions implied by the assumptions about individual behavior and market aggregation are automatically imposed. A further advantage to this procedure is that the dependent variables are those economics purports to predict — prices and quantities. No accounting data are used.

The model treats automobile product type as if it were a scalar, called 'quality'. All consumers agree as to which automobiles are of high quality, but differ in their willingness to pay for auto quality. This heterogeneity of tastes is essential to the demand side of the model; we do not estimate the number of autos a single consumer buys, but rather the number of consumers who find a particular auto model optimal. On the supply side, the model recognizes the multiproduct nature of the automobile firm. The oligopoly solution concept is Nash Equilibrium with prices as strategic variables. Each firm picks a vector of prices for its many products, taking the prices of all other firms as given. Strong functional form assumptions are made about the cost function and about the distribution of tastes across consumers. Under these assumptions, the equilibrium prices and quantities of all products can be explicitly calculated.

In the empirical work, we will use engineering specifications as a proxy for automobile product type. It will therefore be desirable to model the proxy relationship as subject to error. This proxy error will play an important role in assuring the asymptotic properties of maximum likelihood estimation, as well. On the other hand, since auto product quality is unobservable, adding error to it substantially complicates the estimation problem. Estimation will go forward using the E-M algorithm of Dempster et al. (1977). Since that algorithm does not conveniently yield estimates of the parameter standard errors, we calculate standard errors in several different ways, including a sampling experiment.

The empirical results show an average wholesale automobile markup of roughly 10% over marginal cost in each of the 1977–1978 model years. Lower-quality autos tend to have lower markups, higher-quality autos substantially more than 10%. As a result, there is a welfare loss since *relative* auto prices do not reflect relative costs, and consumers' selection among auto models is distorted. This welfare loss is found to be large when compared to the (usual) welfare loss from high price–cost margins overall. The welfare results may be an artifact of the specification; the higher markup at the high-quality end of the auto product spectrum probably are not. Comparisons of our estimates to auto-industry sources suggest the markups reported here are largely correct. There is good evidence that it is

import competition which lowers price–cost margins at the low-quality end of the spectrum.

2. The model

The model has three elements: costs, demand and industrial organization. This section describes those elements and shows how they are used to calculate equilibrium prices and quantities.

2.1. Demand

Automobile purchasers typically buy one unit or none. The demand for automobiles is thus given by the number of buyers and not by the number bought by any hypothetical single consumer. Formally, we assume a continuum of potential buyers, differentiated by tastes. Each consumer chooses some automobile or decides to buy none. Aggregating the decisions of all consumers yields the demand functions for the automobile models.

In this model, different consumers buy different autos not because of differences in income, but because of differences in tastes. The heterogeneity in tastes is modelled in such a way as to yield a demand system for automobile models that is linear in prices. This requires strong assumptions. We assign every consumer a constant marginal rate of substitution between automobile quality and all other goods. Further, that marginal rate is distributed uniformly in the population of consumers. Before we make the assumptions formal, consider the one-dimensional sketch of consumers' product selection in fig. 1. Consumers are labelled by v, their (constant) marginal rate of substitution between automobile product quality and other goods. The vertical lines dividing the consumer space into market segments are those consumers just indifferent between two products; v_{32}, for example, is just indifferent between products 3 and 2. If the price of product 2 were lower, v_{32} would strictly prefer it, and some other consumer would be on the margin between products 2 and 3.

To calculate the marginal consumer in terms of prices, the precise functional form assumed for each consumer's tastes and the distribution of those tastes in the population of consumers are now given.[2] Each consumer

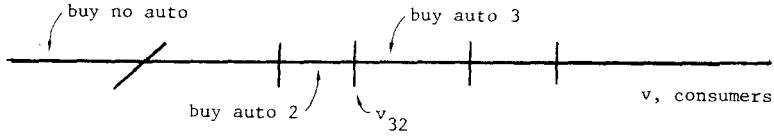

Fig. 1

[2]Prescott and Visscher (1977) use similar assumptions about tastes.

has tastes for automobile quality, x, and for money (not spent on automobiles), Y,

$$U(x,Y,v) = Y + vx, \quad \text{if some auto is bought,}$$
$$= V(Y,v), \quad \text{otherwise.} \tag{1}$$

Consumers differ in their v, but there are equally many with each v,

$$v \text{ is distributed uniformly with density } \delta \text{ on } [0, V_{max}]. \tag{2}$$

δ will become a parameter for econometric estimation. The shape of $V(\ )$ will be discussed below. For the moment, consider the implications of (1) under the assumption that some auto is bought. Let several autos be available, each with price P and quality x. Then consumer v will select that product, j, which minimizes $P_j - vx_j$.

To aggregate individual demand behavior into product demand functions, first calculate the v of the consumer who is just indifferent between two products. Let products h and i have (P_i,x_i) and (P_h,x_h) with $x_i > x_h$. Then consumer v_{hi} is indifferent between h and i iff

$$P_i - x_i v_{hi} = P_h - x_h v_{hi}. \tag{3}$$

Rearranging yields v_{hi} as a function of prices and qualities,

$$v_{hi} = \frac{P_i - P_h}{x_i - x_h}. \tag{4}$$

v_{hi} is truly marginal. All consumers with higher v prefer product i, all with lower v, product h.

To find product i's demand function, let there be another product j with $x_j > x_i$. Calculate v_{ij} exactly as v_{hi}. Then product i is bought by consumers in the interval $[v_{hi},v_{ij}]$ and by none else. Since the density of consumers is δ, the demand function is

$$q_i = \delta[v_{ij} - v_{hi}] = \delta\left[\frac{(P_j - P_i)}{(x_j - x_i)} - \frac{(P_i - P_h)}{(x_i - x_h)}\right]. \tag{5}$$

Note that the difference in qualities, $x_i - x_h$, is an indicator of how close substitutes the products are. The smaller the difference in qualities, the closer the cross-price demand derivative, $(\delta/(x_i - x_h))$, is to the own-price demand derivative, $-(\delta/(x_i - x_h) + \delta/(x_j - x_i))$, in absolute value. In fact, the products are perfect substitutes in the limit as x_i goes to x_h.

The selection of consumers into product market segments is illustrated in fig. 2. The three products have their prices on the vertical axis. The slope of the line through each product's price is (minus) its quality. Thus the lines trace the 'total price' of each product to consumers as a function of tastes, v. Product i is bought by those consumers in the marked interval, since it is

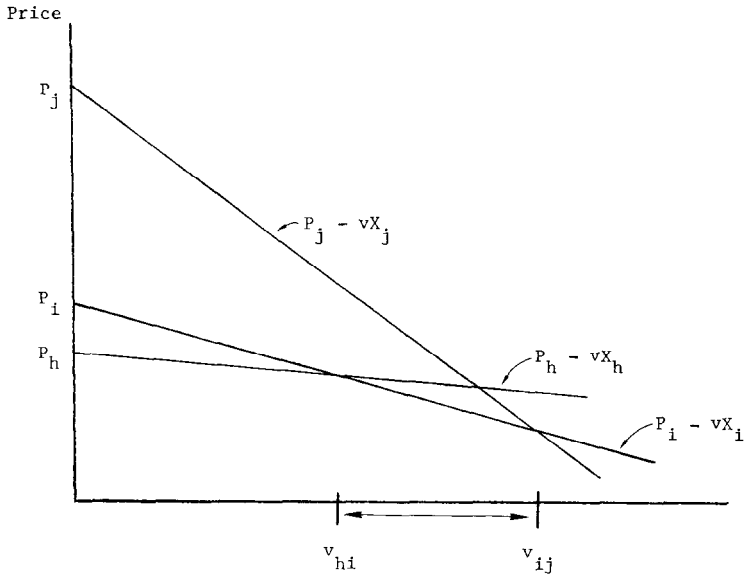

Fig. 2

there that i has the lowest total price. If product i's price were higher, or either of its neighbors lower, the market interval for i would shrink.[3]

That completes discussion of selection of products by those consumers who buy some auto. The other part of the demand functions, the decision whether to buy any auto, is now treated.

The rational consumer deciding whether to buy any auto will compare the utility of the most-preferred auto to utility when no auto is bought. The decision to buy affects utility in three ways. First, there is $\$P$ less to spend on other goods. Second, consumption of automobile quality adds vx directly to utility. Third, the purchase of an auto changes the 'technology' for consuming other goods. This change, reflected in the differences between the two lines of (1) above, is now made specific. We continue to assume that the indirect utility of money in non-automobile uses is linear. But we now assume that the slope and intercept depend on tastes, and change when some auto is bought. That is, the function $V(Y,v)$ in (1) is assumed to take the form

$$V(Y,v)=\max[v\gamma_l-E_l, v\gamma_u-E_u], \quad 0<\gamma_l<x_i<\gamma_u \quad \text{for all } i. \tag{6}$$

[3]In fact, it is clear that the length of the interval is continuous in prices, even at those prices where that length goes to zero. It is also true that product i's demand function is concave across the point at which product $i+1$ is dominated out of the market. These distinctions between 'quality' product differentiation models like this one and 'location' models like that in Hotelling (1929) are the reason that equilibrium prices exist in this model at any fixed qualities, while in Hotelling's they need not.

The E's and γ's are functions of income, tastes and other prices — all constants in our cross-section data. With (1) now completely set, we can calculate the upper and lower consumers just indifferent between buying auto (P,x) and buying no auto,

$$vml(P,x)=\frac{P-E_l}{x-\gamma_l}, \qquad vmu(P,x)=\frac{E_u-P}{\gamma_u-x}. \tag{7}$$

We find the interval of consumers who buy *some* auto by evaluating *vml* at the lowest-quality, *vmu* at the highest-quality auto,

$$vml(P_l,x_l)\leqq v\leqq vmu(P_n,x_n) \quad \text{for all consumers who buy.} \tag{8}$$

Note the formal similarity between (E,γ) in (7) and (P,x) in the formula for v_{ij}, (4). This leads to a natural interpretation of (E_l,γ_l) as the shadow price and shadow quality of a used car. (E_u,γ_u) is similarly interpreted as a car beyond the range of the sample, a sports car, perhaps. The data do not seem to support this interpretation.

That completes specification of the demand side of the model. The demand functions for products 1 to n are

$$q_1=\delta[v_{12}-vml(P_l,x_l)]=\delta\left[\frac{P_2-P_1}{x_2-x_1}-\frac{P_1-E_1}{x_1-\gamma_1}\right], \tag{9}$$

$$q_i=\delta[v_{ui+1}-v_{i-1i}]=\delta\left[\frac{(P_{i+1}-P_i)}{(x_{i+1}-x_i)}-\frac{(P_i-P_{i-1})}{(x_i-x_{i-1})}\right], \tag{10}$$

$$q_n=\delta[vmu(P_n,x_n)-v_{nn-1}]=\delta\left[\frac{E_u-P_n}{\gamma_u-x_n}-\frac{P_n-P_{n-1}}{x_n-x_{n-1}}\right], \tag{11}$$

or, compactly,

$$Q=Q(P,X,E,\gamma,\delta). \tag{12}$$

Some features of the demand system deserve mention. From (10) one can see that incomes do not enter into aggregate model choice — only the distribution of tastes matters. There *is* an income elasticity of demand for new autos overall, though it is hidden in the parameters of (9) and (11). These are strong assumptions, but they correspond roughly to some of the facts about auto demand. The automobile characteristic which is most income-elastic in cross-section is newness. It is much more income-elastic than measures of quality within new cars, such as weight, length, etc.[4] This is not to assert the correctness of our linearity, separability and constant density assumptions, Rather, it is to suggest that they are probably the most reasonable first-order approximation to actual aggregate demand behavior.

[4]See Smith (1975, ch. 5) for the income elasticity of newness. Lave and Train (1979) show that the assertion in the text is not exactly correct globally. In particular, they find a significant relationship between the two largest auto size classes and very high income consumers, as one might suspect.

2.2. Costs and industrial organization

This section describes the cost and profit functions for a multiproduct oligopolist. The oligopoly solution concept is outlined and the equations defining equilibrium prices and quantities are presented. These will later become the estimating equations in the empirical work.

In order to treat multiproduct firms, we will need separate notation for the firm (usually k) and the product (usually j). With firm k we associate the vector of products it sells, X_k, and the quantities in which they are made, Q_k. The firm also has associated with it a set of indices for the products it sells, $J_k : j \in J_k$ if firm k produces product j. One further notational convention: uppercase is used for vectors of qualities and quantities (X_k, Q_k), lowercase for scalars (x_k, q_k).

With that notation in hand, we describe the cost function. All firms have access to the same technology. Costs depend on the number of products made, their quantities and qualities. The dependence on quantities is assumed to take the fixed cost plus constant marginal cost form

$$C(X_k, Q_k, n_k) = A(n_k, X_k) + \sum_{j \in J_k} mc(x_j) q_j. \tag{13}$$

In Bresnahan (1980) it was shown that if $A(\ )$ is continuous, $mc(\ )$ strictly increasing and strictly convex, then a two-stage equilibrium exists. Further, the equilibrium has the property that all products in which some firm has invested the capacity to produce are sold in positive quantity. We now set a functional form for marginal cost. A one-parameter form fulfilling the conditions is the exponential

$$mc(t) = \mu\, e^t, \tag{14}$$

where μ is a parameter to be estimated. The exponential form is arbitrary, but follows the success of the log-linear hedonic models. No specific assumptions about the fixed-cost function, $A(\ )$, are made, since its parameters are not identified by the estimation procedure in this paper. Only that part of the model having to do with price/quantity equilibrium is estimated here.

That completes specification of the economic relations of the model. We now move toward solution for the equilibrium prices and quantities by specifying the profit function for firm k,

$$\Pi_k(P, X) \equiv \sum_{j \in J_k} (P_j - mc(x_j)) \cdot q_j(P, X) - A(n_k, X_k), \tag{15}$$

where the dependence on parameters has been momentarily suppressed. The solution concept for the Stage II (price/quantity) game is Nash equilibrium with prices as strategic variables. Note that the profit function (15) is quadratic in prices, since the demand functions are linear. Thus we will be able to differentiate (15) with respect to prices, and the resulting equilibrium relations will be linear. This is the key to solving for equilibrium P and Q in closed form.

To be able to write price derivatives of (15) in convenient form, we need to condense the notation for firms and products. Define an n by n matrix of corporation dummy variables, C. C has ones only in those entries where row and column products are sold by the same firm,

$$\begin{aligned} C_{ij} &\equiv 1, \quad \text{if} \quad i \in J_k \quad \text{and} \quad j \in J_k \quad \text{for some } k, \\ &\equiv 0, \quad \text{otherwise.} \end{aligned} \tag{16}$$

In this notation, the first-order condition for a typical product, i, is

$$\begin{aligned} 0 = q_i + (P_i - mc(x_i))\frac{\partial q_i}{\partial P_i} + C_{ii+1}(P_{i+1} - mc(x_{i+1}))\frac{\partial q_{i+1}}{\partial P_i} \\ + C_{ii-1}(P_{i-1} - mc(x_{i-1}))\frac{\partial q_{i-1}}{\partial P_i}. \end{aligned} \tag{17}$$

To solve for equilibrium prices and quantities, write out (17) for all products simultaneously.[5] Then substitute for q_i using (9)–(11). This is the system of equations which the equilibrium prices must satisfy

$$p_1\Gamma_{11} + p_2\Gamma_{12} = \Delta_1, \tag{18}$$

$$p_1\Gamma_{21} + p_2\Gamma_{22} + p_3\Gamma_{23} = \Delta_2, \tag{19}$$

$$\vdots$$

$$p_{i-1}\Gamma_{ii-1} + p_i\Gamma_{ii} + p_{i+1}\Gamma_{ii+1} = \Delta_i, \tag{20}$$

$$\vdots$$

$$p_{n-1}\Gamma_{n-1n} + p_n\Gamma_{nn} = \Delta_n. \tag{21}$$

That is, $p\Gamma = \Delta$, where

$$\Gamma_{ii+1} = \Gamma_{i+1i} = \frac{1 + C_{ii+1}}{x_{i+1} - x_i}, \qquad i = 1, \ldots, n-1, \tag{22}$$

$$\Delta_1 = -mc(x_1)\left[\frac{1}{x_1 - \gamma_l} + \frac{1}{x_2 - x_1}\right] + mc(x_2)\frac{C_{12}}{x_2 - x_1} - \frac{E_l/\delta}{x_1 - \gamma_l}, \tag{23}$$

$$\begin{aligned} \Delta_i = -mc(x_i)\left[\frac{1}{x_{i+1} - x_i} + \frac{1}{x_i - x_{i-1}}\right] + mc(x_{i+1})\frac{C_{ii+1}}{x_{i+1} - x_i} \\ + mc(x_{i-1})\frac{C_{ii-1}}{x_i - x_{i-1}}, \qquad i = 2, \ldots, n-1, \end{aligned} \tag{24}$$

$$\Delta_n = -mc(x_n)\left[\frac{1}{x_n - x_{n-1}} + \frac{1}{\gamma_u - x_n}\right] + mc(x_{n-1})\frac{C_{nn-1}}{x_n - x_{n-1}} - \frac{E_u/\delta}{\gamma_u - x_n}. \tag{25}$$

[5]It is tedious to actually prove that simultaneously solving the first-order conditions yields the equilibrium prices and quantities. The pitfall lies in the possibility of one firm setting its prices so that some other firm's product sells no units, in which case (9)–(11) are not the actual demand system. It is shown in Bresnahan (1980) that the first-order conditions are sufficient for the unique equilibrium.

The diagonal elements of Γ are $2/\delta$ times the own-price derivative of the product demand functions

$$\Gamma_{11} = 2\left[\frac{-1}{x_1 - \gamma_l} - \frac{1}{x_2 - x_1}\right], \tag{26}$$

$$\Gamma_{ii} = 2\left[\frac{-1}{x_{i+1} - x_i} - \frac{1}{x_i - x_{i-1}}\right], \qquad i = 2, \ldots, n-1, \tag{27}$$

$$\Gamma_{nn} = 2\left[\frac{-1}{x_n - x_{n-1}} - \frac{1}{\gamma_u - x_n}\right]. \tag{28}$$

All other elements of Γ are zero,

$$\Gamma_{ml} = 0, \qquad |m-l| > 1, \tag{29}$$

Let us introduce a slightly more compact notation for the parameters of the costs and demand systems,

$$\theta \equiv (E_u, \gamma_u, E_1, \gamma_1, \delta, \mu)'. \tag{30}$$

Then use (22)–(28) to compute the equilibrium prices, P^*,

$$P^*(X,\theta) = \Delta\Gamma^{-1}. \tag{31}$$

The equilibrium prices are then substituted back into the demand functions (9)–(11) to calculate equilibrium quantities

$$Q^*(X,\theta) = Q(P^*(X,\theta),\theta). \tag{32}$$

We will use eqs. (31) and (32) as the central regression relations in the empirical work. They are used to calculate predicted prices and quantities in terms of the cost and demand parameters and of the vector of qualities.

3. Econometric considerations

This section treats the econometric specification of the model, the data, and the estimation method. The error structure and the proxies for quality are discussed. The estimation method is maximum likelihood by the E-M method of Dempster et al. (1977) which is explained here.[6] A subsection reviews the asymptotic properties of the MLE; we will need a few paragraphs to see that the regularity conditions are satisfied.

3.1. Proxies, errors and the likelihood

The central regression relation for this paper is the equilibrium mapping (31) and (32). The stochastic structure of these equations is specified by

[6]The technique has several other uses in econometrics. See for example Hartley (1978).

adding independent normal error,

$$P_i = P_i^*(X,\theta) + \varepsilon_{pi}, \tag{33}$$

$$q_i = q_i^*(X,\theta) + \varepsilon_{qi}. \tag{34}$$

This error is to be interpreted as pure observation error, an interpretation that is consistent both with the reduced-form nature of the error and the independence assumptions. The stochastic specification is completed by the proxy relationship for X. Automobile product quality, an unobservable, is assumed to be a function of observables and of random error. Let z_i be the vector of attributes of automobile i. Then let

$$x_i^*(z_i,\beta) = \sqrt{\beta_0 + \sum_j z_{ij}\beta_j} + \varepsilon_{xi}, \tag{35}$$

where β are parameters to be estimated. The interpretation of the proxy relationship comes from the equilibrium model of hedonic prices; Rosen (1974). The β's contain information about both tastes and technology in that model, so that their interpretation here is unclear. The square-root functional form is arbitrary, but is intended to capture decreasing returns to each individual attribute; a car twice as long should not be twice as good.

All three errors are normal. They are independent across-equations[7] and across-observations (models). We label the variance of $\varepsilon_{xi}\sigma^2 x$, of $\varepsilon_{pi}\sigma_p^2$ and of $\varepsilon_{qi}\sigma_q^2$. Calling all three variances Σ, the likelihood function for the vectors P, Q, and X is

$$\begin{aligned} L_3(P,Q,X,\theta,\beta,\Sigma) \equiv & [(2\Pi)^3 \cdot \sigma_P^2 \cdot \sigma_q^2 \cdot \sigma_x^2]^{-n/2} \\ & \times \exp\{-\tfrac{1}{2}[(P - P^*(X,\theta))'(P - P^*(X,\theta))/\sigma_P^2 \\ & + (Q - Q^*(X,\theta))'(Q - Q^*(X,\theta))/\sigma_q^2 \\ & + (X - X^*(Z,\beta))'(X - X^*(Z,\beta))/\sigma^2 x]\} \end{aligned} \tag{36}$$

since the Jacobian of the transformation from ε to X,P,Q is unity. The 3 in L_3 represents the 3 dependent variables.

Two problems arise in using L_3 as the likelihood function. First, $Q^*(X,\theta)$ is discontinous[8] in X at points like $x_j = x_i$. This is clear from (9)–(11), where computation of quantities involves division by $(x_i - x_j)$. Second, L_3 cannot be calculated, since it contains the unobservable qualities, X. Both of these problems are now solved in the same way. We must integrate X out of L_3 to

[7]A specification with $E[\varepsilon_{pi} \cdot \varepsilon_{qi}]$ not necessarily zero was considered. It was not estimated because the sampling correlation between the residuals from the price and the quantity equations was 0.09 in 1977 and −0.16 in 1978. Covariances between quality errors and those in the other equations are certainly not identified, since quality is unobservable.

[8]The existence of the discontinuity was shown in Bresnahan (1980). Continuity of $P^*(\dot{X},\theta)$ was also shown.

obtain the marginal likelihood of the observed data,

$$L_2(P,Q,\theta,\beta,\Sigma) \equiv \int_{R^n} L_3(P,Q,X,\theta,\beta,\Sigma)\,dX. \tag{37}$$

We will show below that this integration leaves L_2 continuous in the parameters. Note that L_2 was defined by a nonlinear multivariate normal integral. Thus it will not be possible to express L_2 in closed form. This leads to a fairly involved procedure in computing the MLE.

3.2. Estimation procedure

Maximum likelihood estimates were obtained using the E-M algorithm of Dempster et al. (1977). This algorithm uses an iterative procedure to maximize likelihoods defined by the integration out of an unobservable, like X in the present problem. The scheme begins with an initial estimate[9] $(\theta^0,\beta^0,\Sigma^0)$. Then each iteration, i, of the procedure has two steps:

E-step: The unobservable, X, is set equal to its conditional expectation at the current parameter vector,

$$X^i = E[X \mid P,Q,\theta^{i-1},\beta^{i-1},\Sigma^{i-1}]. \tag{38}$$

M-Step: The parameter estimates are updated by maximizing the full-data likelihood, L_3, treating X^i as if it were data,

$$(\theta^i,\beta^i,\Sigma^i) \text{ maximizes } L_3(P,Q,X^i,\theta,\beta,\Sigma). \tag{39}$$

Dempster et al. (1977) show that this procedure converges to a maximum of the observable-data likelihood L_2.

Why evaluate the expectation (38) rather than the exact likelihood L_2? Each involves a complicated integral, and neither can be solved in closed form. In the present paper, both kinds of integrals were computed by Monte-Carlo integration. L_2 cost approximately 100 times as much to integrate as (38) on the computer. Thus maximization of the likelihood by the E-M method cost about a fifth as much as numerical differentiation of the likelihood function to obtain asymptotic standard errors.

3.3. Asymptotic considerations

The discontinuity of Q^* in qualities and the resulting discontinuity of L_3 in β open to question the regularity conditions for consistency and asymptotic normality of the MLE. Two of the conditions are affected. First, is the likelihood L_2 everywhere continuous in the parameters? Second, is it

[9]Obtained in the present paper by setting the quality variance to zero and solving the resulting nonlinear regression problem.

smooth around the true parameter value, so that a Taylor series can be taken there? We show that the answer for L_2 is yes on both counts.

Continuity of L_2 follows from elementary arguments in analysis. The definition of L_2 by an integral assures its continuity. The conditions for this are[10] that L_3, viewed as a function of X^* and ε_x only, be measurable and be bounded by an integrable function for all X^*. Measurability is easy: L_3 is piecewise continuous with only finitely many discontinuities. Boundedness is also easy. With Σ fixed, L_3 is bounded above by $[(2\Pi)^3 \cdot \sigma_P^2 \cdot \sigma_q^2 \cdot \sigma_x^2]^{-n/2}$ and below by zero.

Smoothness of L_2 must be established by economic arguments. This is not surprising, since it is at the true parameter value that we wish to take the Taylor series. Economically, the condition to ensure smoothness is that no two qualities be identical. At all other points in the parameter space, there is no difficulty in differentiating the likelihood function infinitely many times. But consider the product type selection process for firms. It was shown in Bresnahan (1980) that points like $x_i = x_j$ are local minima of the profit functions for the firm(s) making products i and j. This ensures that such points will not occur in equilibrium. The intuition of this result is straightforward — investment in a particular product looks worst when it will compete against perfect substitutes.

3.4. The data

All data on automobile model prices, quantities and characteristics come from industry trade journals. Precise definitions are given in the appendix. Briefly, prices are list wholesale prices for the basic model without options. Quantities are model year production for domestic manufacturers, October–September sales for foreign ones. The product specifications used to proxy quality are length (inches), weight (pounds), engine horsepower and number of cylinders, gallons/mile (EPA city estimate) and two body-type dummies.

Two comments on data handling seem appropriate. First, the treatment of foreign products is arbitrary. This is unavoidable, since foreign manufacturers do have some different practices from domestic ones, particularly regarding the model year. Section 5 reports some ad hoc attempts to test the assumption that foreign and domestic producers can be treated the same. Second, the use of wholesale prices implicitly assumes a perfectly competitive auto retail market. The rationale for the use of wholesale prices is the expectation that list wholesale prices are generally closer to transaction prices then their retail counterparts. One opportunity for divergence of list from transaction prices comes late in the model year, when manufacturers share their dealers' capital losses on models that have not sold well. In the

[10]See e.g. Royden (1968, p. 93, #24).

sample, dealer inventories were uncomfortably large at the end of the 1977 but not the 1978 model year. Use of wholesale prices and exclusion of options from the data is probably conservative relative to the conclusions of this paper. Changing either of those procedures would almost certainly increase the estimated markups, particularly at the high-quality end of the product spectrum.

4. Empirical results

This section reviews parameter estimates, evaluates their economic significance, and compares methods for obtaining standard errors.

4.1. The estimates

Table 1 reports maximum likelihood estimates of the parameters for the 1977 and 1978 model years. A preliminary calculation will help interpret parameter values. The range of x across models, as indicated by $Z\beta$, takes on the values (3.2, 4.6) in 1977 and (2.9, 4.5) in 1978. Thus in each year the

Table 1
Parameter estimates.[a]

		1977		1978	
θ	E_u	1.65E5	(3.09E4)	1.97E5	(3.95E4)
	γ_u	2.84E1	(1.79E1)	4.22E1	(1.24E1)
	E_t	1.47E3	(4.80E2)	2.01E3	(1.97E2)
	γ_t	3.15	(1.45E−1)	2.89	(2.04E−1)
	δ	6.94E2	(2.71E1)	5.91E2	(5.14E1)
	μ	1.39E2	(2.24E1)	1.56E2	(5.25E1)
β	Constant	3.59E−3	(1.60E−3)	3.36E−3	(8.95E−4)
	Length	2.44E−5	(3.08E−5)	1.20E−5	(2.66E−5)
	Weight	1.08E−3	(4.25E−4)	6.14E	(3.87E−4)
	Cylinders	−2.51E−3	(1.62E−3)	−1.80E−3	(2.57E−3)
	Horsepower	5.59E−2	(1.87E−2)	4.33E−2	(3.74E−2)
	Gals/mile	−3.18E−2	(4.74E−3)	−3.22E−2	(1.07E−2)
	Hardtop	−1.41E−1	(3.16E−2)	7.84E−2	(1.93E−2)
	Hatchback	−7.43E−2	(3.37E−2)	−1.09E−1	(2.53E−2)
Σ	σ_p^2	4.14E5	(2.38E4)	5.52E5	(3.07E4)
	σ_q^2	4.66E7	(3.78E6)	5.03E7	(4.09E6)
	σ_x^2	5.76	(6.21E−1)	4.48	(4.09E−1)
R_p^2		82		81	
R_q^2		74		75	
R_x^2		94		94	
Sample size		184		191	

[a]Figures in parentheses are asymptotic standard errors.

Table 2[a]

	$-\delta/(\gamma_u - x_n)$	$-\delta/(x_l - \gamma_l)$
1977	2.91 (8.47)	1.39E4 (8.14E3)
1978	15.6 (79.9)	9.63E4 (1.53E3)

[a]Asymptotic standard errors in parentheses.

highest-quality auto had about 1.5 times the predicted quality of the lowest-quality auto.

One important role of the parameters γ is determination of the slopes of the demand functions of the extremal products — that part which comes from not buying any car. [See (9)–(11) above.] This slope depends on the difference between γ and the quality of the extremal vehicle. (See exact formulae in the top line of table 2.) An interesting hypothesis in this context is that the strongest preferrers of auto quality always buy some auto. Thus nearly all substitution out of new automobiles comes at the low end. To test this 'filtering' hypothesis, the relevant slopes are calculated in table 2 for the top (left column) and bottom of the automobile market. At the high end, a one-dollar increase in product prices drives only a few consumers to leave the auto market. Standard errors indicate that this effect is statistically as well as economically insignificant. Substitution out of new automobiles is substantial at the low end, by contrast.

Let us tighten the interpretation of the parameters E and γ by recalling the formal equivalence of the (E,γ) pair and the price and quality of a hypothetical auto product. Since there are no exogenous variables on the demand side in this paper, demand is merely effective demand. It is therefore possible that the substitution out of new automobiles is being driven by a perfectly competitive used-car market. At the low end, the interpretation is consistent with the parameters. (E_l, γ_l) describes an 'auto' with lower quality that any new car and price about half or two-thirds of the cheapest new car. At the upper end, this story is implausible. The mythical auto has an order of magnitude higher quality than any real auto, and is priced in the hundreds of thousands of dollars.

δ, the density of tastes, is estimated to be quite small. The volume of automobile buyers is over 10 million; a density between 600 and 700 implies a distribution of tastes that is very much more wide than it is deep. This degree of heterogeneity in tastes for automobiles should probably not be surprising in light of the diversity of models available on the market. Together, the parameters θ imply an industry demand elasticity[11] of around 0.25, and an elasticity for the average product of 3.2.

[11]All elasticities are evaluated at equilibrium prices and quantities. Industry elasticity refers to a proportionate change in all prices. Product elasticity assumes that the prices of all other products remain the same.

Overall, the parameter subvector θ shows 1977 and 1978 as fairly similar years. The calculation of the range of $Z\beta$ above also showed stability. Finer inspection of the β subvector shows serious changes year-to-year as well as some anomalies. Only the constant and the gasoline–mileage parameter are stable over time. Presumably the reason for the instability in the parameters is the new model introductions in 1978. There are also a few surprises in the signs and orders of magnitudes of a few estimated parameters. That the two body-type dummies are so large relative to the constant is alarming. And the negative coefficient on 'cylinders' is a surprise. The econometric rationale for this is that horsepower, cylinders and gallons/mile are highly collinear. An old story, that cylinders numbers pick up engine efficiency, does not seem to go in the presence of the mileage figure. All in all, it does not seem reasonable to draw conclusions about the shape of tastes or technology from the β estimates in this paper. The peculiar signs and time-instability argue too strongly against it.

Inspection of the variance estimates and R^2 shows fairly respectable fit for auto cross-section. Compared to Bresnahan's (1980) results (on data from the mid 1950's) the current estimates fit the quantity equation better and the price equation worse. This is not surprising in light of the exit of small producers and their replacement by foreign competition. The R^2's for the price and quantity equation reported here come from the M-Step, so they are conditional on the expected value of X.

4.2. *Standard errors*

Maximum likelihood by the E-M method never explicitly calculates the likelihood function or its derivatives. This leaves two natural methods for estimating the asymptotic standard errors of the estimated parameters. One method calculates the likelihood L_2 in order to differentiate it numerically. The other performs the natural sampling experiment. These two methods are compared in this section and found essentially identical. Two other methods with no theoretical justification are calculated as well. Table 3 reports these four methods for the parameter variances for model 1 on the 1977 data.

The first column ('sampling') reports a modest sampling experiment. Once the maximum likelihood estimates were obtained, they were used to generate random data.[12] The new data were used to compute a new MLE (by E-M). 150 repeats of this procedure yielded the parameter variances reported under 'sampling', as well as the exact standard errors reported above for various functions of the parameters.

Many econometricians without computational experience are troubled by

[12]Normal random variates were generated by the Box–Muller method.

Table 3
Alternative parameter variance estimates for model 1 — 1977.

	Sampling	$\partial^2 L/\partial^2$	M-step	1-step
E_u	9.55E8	9.81E8	6.91E8	1.06E9
γ_u	3.20E2	2.74E2	2.57E2	3.37E2
E_l	2.30E5	2.51E5	1.97E5	2.27E5
γ_l	2.10E−2	2.38E−2	1.97E−2	2.26E−2
δ	7.34E−2	7.37E−2	6.78E−2	7.84E−2
μ	5.02E2	4.54E2	3.67E2	5.43E2
Constant	2.56E−6	2.37E−6	2.29E−6	3.12E−6
Length	9.49E−10	1.05E−9	7.89−10	7.84E−10
Weight	1.81E−7	1.80E−7	1.31E−7	2.02E−7
Cylinders	2.62E−6	2.35E−6	1.45E−6	2.17E−6
Horsepower	3.48E−4	3.24E−4	2.09E−4	4.73E−4
Gals/mile	2.24E−5	2.50E−5	1.72E−5	2.93E−5
Hardtop	9.98E−4	1.03E−3	8.10E−4	1.17E−3
Hatchback	1.13E−3	1.16E−3	8.28E−4	1.15E−3
σ_p^2	5.66E8	5.04E8	2.81E8	6.40E8
α_q^2	1.43E13	1.56E13	1.28E13	1.51E13
α_x^2	3.86E−1	3.04E−1	3.47E−1	4.06E−1

variance estimates from a sampling experiment. They expect numerical maximization procedures to 'stop too soon'. The fourth column of table 3 ('1-Step') is designed to put these fears to rest. These are from the same sampling experiment as column one, except that the E-M algorithm is not allowed to converge in column four, but forced to stop after one complete step. (The starting point was the 'true' parameter value, of course.) It is easy to see that this one-step method systematically overstates, not understates, the parameter variances.

Column two ($\partial^2 L/\partial^2$) reports variance estimates from the second derivatives of the loglikelihood function. This was calculated by numerical differentiation of the (numerically integrated) observable-data likelihood L_2. These asymptotic standard errors seem pretty close to the exact standard errors in column one.

Column three ('M-Step') reports an unreliable estimate. Suppose that in maximizing L_3 in the M-Step of the E-M algorithm, standard errors as well as parameter estimates were calculated. For example, the estimated variance–covariance matrix of β would be

$$\sigma_x^2 \cdot (Z'Z)^{-1} Z'X^i, \tag{40}$$

if i were the last iteration of the E-M algorithm. The variances of the rest of the parameters come from similar calculations. This method universally understates the variances. This result is not surprising — parameter variances should fall if X were known.

5. Economic implications

This section investigates some implications of the parameter estimates. Topics are the price–cost margin at different points in the quality spectrum, welfare losses, and the role of imports.

5.1. Price–cost margins

Fig. 3 shows the story of automobile market equilibrium told by the estimated parameters. The horizontal axis has predicted product quality. The vertical axis is in the logarithmic scale; predicted prices and estimated marginal costs are plotted. Note that typical markups are much higher at the high-quality end of the auto quality spectrum. This is as reported by automobile manufacturers, a point to which we shall return in a moment. Note further the products are much more tightly bunched at the low-quality end of the product spectrum. This greater bunching, then, is our explanation of the low markups at the low end. The model's measure of product differentiation is $1/(x_i - x_j)$. On this measure, the estimates have low-quality autos typically competing against much closer substitutes than more expensive models. This closer competition leads to equilibrium prices nearer marginal cost.

Table 4 gives this relationship between closeness of substitutability and price–cost margins in a different way. For each quartile[13] of the product–quality distribution, the table presents closeness of substitutes, marginal cost, and the price cost markup. For product j, closeness of substitutes is defined as $1/(x_j - x_{j-1}) + 1/(x_{j+1} - x_j)$, marginal cost ($mc$) is $\mu \exp(x_j)$, and the markup is (predicted price $- mc)/mc$. The table reports the simple averages of these within each quartile. The 'range' column gives the qualities of the products at the extremes of each quartile. Note that lower quality vehicles are the closer substitutes, lower costs, and smaller markups.

Some idea of the reliability of this description of auto market equilibrium can be found in table 5. This table reports estimates of marginal cost and price–cost margins for four groups of Ford models.[14] The first column reports the estimates implied by the model. The second column was compiled by the author from an internal Ford Motor Company memorandum. The two columns seem roughly consistent; marginal cost is slightly overestimated in this paper, price–cost margins underestimated. But there does not appear to be any consistent bias in the pattern of estimated markups. The

[13]'Quartile' here refers to 25% of the models, not of sales.

[14]Within each group, reported figures are simple averages across models. There are more models than names, as different engines, trimlines, etc. were treated as different in the estimates when the data permitted. Grouping is necessary to preserve confidentiality of the Ford data. Further, the sampling variation is such that our estimated markup for a single model is unreliable.

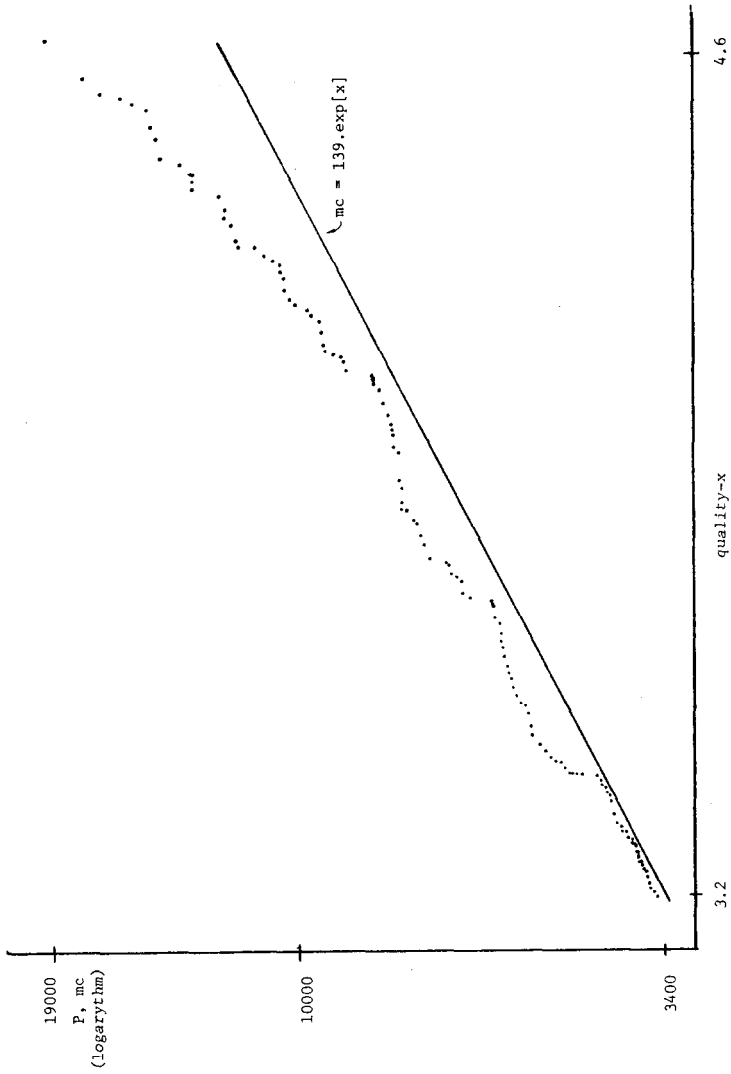

Fig. 3. Predicted price (·) and *mc* (—) for 1977.

Table 4
Marginal cost, markup and closeness of substitutes by quality.

		Range	mc	$(P-mc)/mc$	cs
1977	$x_1 - x_{47}$	3.2–3.4	3841	0.04	641
	$x_{47} - x_{93}$	3.4–3.6	4726	0.09	520
	$x_{93} - x_{138}$	3.6–4.1	6537	0.18	235
	$x_{139} - x_{184}$	4.1–4.6	8521	0.24	221
1978	$x_1 - x_{48}$	2.9–3.2	3694	0.05	594
	$x_{49} - x_{96}$	3.2–3.4	4603	0.09	431
	$x_{97} - x_{144}$	3.4–4.0	6817	0.16	287
	$x_{145} - x_{191}$	4.0–4.5	8742	0.25	230

large markups are at the high-quality end of the spectrum in both sets of figures. This will be the key to the reported welfare-economic results of the next section.

5.2. *Welfare losses*

The price–cost margins reported in tables 4 and 5 suggest the possibility of a welfare loss.[15] With product differentiation, two potential sources of welfare loss arise. The first is labelled the 'usual' loss. This is the gain from trade foregone because some consumers who would buy an automobile at marginal cost do not do so at equilibrium prices. The second source is labelled the 'within' the industry welfare loss. This arises among consumers

Table 5
Marginal cost and markup on selected autos — 1977.

	Estimated		Ford	
	mc	$P-mc$	mc	$P-mc$
Subcompacts[a]	3544	231	3287	512
Compacts[b]	3909	361	3628	632
Intermediates[c]	4231	573	3936	811
Large[d]	5275	1442	4940	1818

[a]Pinto, Bobcat, Mustang II; 9 models.
[b]Except Granada. Monarch, Maverick, Comet; 8 models.
[c]Includes Granada. Also Cougar, LTD II; 7 models.
[d]LTD, Marquis, all Lincolns; 8 models.

[15]Defined here in the first-best sense of comparing equilibrium prices to marginal costs. No allowance is made for producers' inability to cover their (large) design/development fixed costs in a marginal-cost pricing regime.

who do buy some auto, but are led by equilibrium prices to buy socially inefficient autos. The *pattern* of markups in the tables — much higher markups at one end of the product quality spectrum — suggest the importance of this 'within' welfare loss.

Our welfare loss criterion leaves the set of products available in the market the same. We investigate only the effects of departures of prices from marginal cost. Producers would lose in a marginal-cost pricing regime, of course. Under the constant marginal cost assumption, the change in profits to the producer of product i is $(P_i^* - mc_i)q_i^*$, where P^* and q^* are the predicted equilibrium price and quantity. The total change in profits is calculated by summing over all products.

For the individual consumer, exact welfare analysis is straightforward in the present context. As in any quantal-choice problem, what has been estimated is the indirect utility function. Under the linearity and separability assumptions used in estimation, the indirect utility function is easily inverted to get the expenditure function. The exact welfare change between two price regimes for person v is calculated as the difference in the expenditure functions,

$$\Delta \exp(v,P_1,P_2) = P_{1v} - P_{2v} + v(x_{2v} - x_{1v}), \tag{41}$$

where (P_{iv},x_{iv}) is the auto bought by person v in regime i. For non-buyers, (P_{iv},x_{iv}) is (E,γ). (41) reports an entirely sensible result: if price distortions lead no consumer to change the auto bought, then there will be no welfare loss. For each consumer, (41) is calculated with one price vector set to the predicted equilibrium prices, the other, to estimated marginal costs. (41) is then integrated over all consumers, giving the exact total loss to consumers from the departure from marginal cost. The 'usual' loss to consumers is calculated by comparing differences in (41) for only those consumers who do buy an auto in the marginal cost regime, but who buy none in equilibrium.

Table 6 gives the results of these calculations. Producers' surplus for the entire industry is over \$4billion in each model year. Consumers' losses are larger, at over \$7billion in each year. Of these, only a small fraction are attributable to the 'usual' source of loss. By far the greater portion comes from the 'within' welfare loss. The resulting total welfare loss is over \$3billion in each model year, or about 7.8% of revenues.

The welfare loss reported in table 6 is quite large — roughly 9 times (in constant dollars) that found by Siegfried and Tiemann (1974). One possible explanation of this is the importance of taking the product differentiation effects into account. But is is worthwhile to consider the reliability of the present calculations at some length.

Three kinds of issues arise in assessing the reliability of our welfare loss figures. First are statistical issues. Although the total welfare loss is estimated precisely, neither producers' surplus nor consumers' loss exceeds its

Table 6
Welfare loss calculation.[a]

	1977	1978
Unit sales	10.3	10.4
Total revenue	39.9	42.8
Producers' surplus	4.11 (3.5)	4.36 (3.4)
Consumers' loss		
Total	7.23 (6.8)	7.68 (6.8)
'usual'	0.71 (0.56)	0.82 (0.62)
Welfare loss	3.12 (0.94)	3.32 (0.96)

[a]Asymptotic standard errors are in parentheses. Revenue, surplus and loss figures are in $billions; unit sales in $millions.

standard error. This suggests caution, as it must be driven by a second-order effect, the estimated covariance of the producers' gain and the consumers' loss. A second set of reliability issues has to do with data handling. Excluding sports models, station wagons, etc. is probably conservative relative to the conclusions. Similarly, defining prices at the wholesale level is conservative, as dealers get much larger markups on high-end autos. Excluding the prices of options is more complex. Simply adding in an average expenditure on options per model would raise the estimated welfare loss, since options are priced much higher from marginal cost than is the basic auto. Yet this ignores the role of options as a monitoring device in price discrimination, a role in which their welfare effects are ambiguous.

The most important set of reliability considerations have to do with the model. One might worry that the welfare results are an artifact of the specification. A strong case can be made against the one-dimensional distribution of consumer tastes in this regard. It would be reasonable to ask the model to allow tastes for 'newness' of autos to vary separately from tastes for 'quality'. Certainly, then, a larger number of consumers would be near the buy-no-new auto margin. The fraction of the welfare loss attributed to 'within' would fall, and that to 'usual' would rise.

Yet it is not obvious that this change would have a large effect on the total welfare loss. What is driving the 'within' loss is the high markups at the high-quality end of the auto product spectrum. Those are very real, independent of the specification in this paper. Another way to see this is to think in terms of the 'usual' welfare loss. Our estimates show inelastic demand for *all* automobiles, and a small average markup. Yet if we looked at high-quality autos *only*, we would see elastic demand (because of the existence of a close substitute — other autos) and a large markup. Thus we

are not surprised to find that taking product-differentiation into account is important in assessing performance.

Many model features — separability of tastes, constant marginal costs — do not have obvious effects on the results. The oligopoly solution concept, on the other hand, is conservative relative to the welfare figures. That concept had prices as strategic variables (Bertrand). Quantities (Cournot) or a collusive solution concept would have moved prices farther from marginal costs.

5.3. *The role of imports*

The import[16] models which sell in large quantity are concentrated in the low-quality end of the product spectrum. Is it import competition, then, which accounts for the low markups in that end? The estimates suggest that it is. Table 7 reports the results of a conceptual experiment in which all imported automobiles are banned. In this experiment, equilibrium prices for domestic vehicles rise because of lessened competition. In the model, this is reflected in the fact that the typical value of $1/(x_i - x_j)$ rises when imports are deleted. Comparing table 7[17] we find that the effect on prices is unimportant at the high-quality end. Markups rise at most a few percentage points. At the low-quality end, by contrast, markups seem to rise by over five percentage points. The effect of banning imports is to substantially lessen competition, but only at the low-quality end of the market.

Table 7
Markup and closeness of substitutes by quality domestic autos only.

	1977		1978	
Quartile	$(P-mc)/mc$	*cs*	$(P-mc)/mc$	*cs*
I	0.10	412	0.11	391
II	0.13	384	0.13	356
III	0.21	217	0.20	210
IV	0.26	180	0.26	195

Is this effect of imports the result of some difference between imported and domestic models which has been ignored in the estimates? We check this conjecture by reestimating the model with some dummy variables for foreigness. Estimates of foreigness specifications on both the cost and the quality parameters, for both 'Japanese' and 'all non-U.S.' variants, are reported for both model years in tables 8 and 9.

[16]Throughout this section, imports are defined to exclude all autos made in Canada, but to include captive imports.

[17] Table 7 reports the equivalent of the last two columns of table 4, markup and closeness of substitutes. These are calculated for the same ranges of quality in both tables. Only domestic autos are included in table 7, of course.

Table 8
Alternative models of import distinctness — 1977.

	Model 1	Model 2	Model 3	Model 4	Model 5
E_u	1.65E5 (3.09E4)	1.65E5 (3.03E4)	1.87E5 (2.85E4)	2.19E5 (3.16E4)	1.38E5 (3.38E4)
γ_u	2.84E1 (1.79E1)	.62E1 (1.72E1)	2.37E1 (2.04E1)	4.79E1 (1.92E1)	3.02E1 (1.76E1)
E_l	1.47E3 (4.80E2)	1.21E3 (4.52E2)	1.57E3 (4.18E2)	1.54E3 (5.14E2)	8.11E2 (4.54E2)
γ_l	3.15 (1.45E−1)	2.98 (1.56E−1)	3.03 (1.71E−1)	2.99 (1.68E−1)	3.44 (1.22E−1)
δ	6.94E2 (2.71E1)	5.36E2 (2.71E1)	8.71E2 (2.64E1)	4.30E2 (2.79E1)	6.17E2 (2.74E1)
μ	1.39E2 (2.24E1)	1.40E2 (2.29E1)	1.42E2 (2.10E1)	1.38E2 (2.05E1)	1.39E2 (2.01E1)
μ_f		−4.18E−1 (5.42E1)			
μ_j			−5.80E−1 (7.17E1)		
Constant	3.59E−3 (1.60E−3)	2.25E−3 (1.64E−3)	5.00E−3 (1.47E−3)	1.87E−3 (1.46E−3)	1.43E−3 (1.39E−3)
Length	2.44E−5 (3.08E−5)	7.28E−5 (3.18E−5)	3.30E−5 (2.66E−5)	3.84E−5 (3.16E−5)	9.89E−5 (2.78E−5)
Weight	1.08E−3 (4.25E−4)	9.66E−4 (4.21E−4)	1.19E−3 (4.32E−4)	4.61E−4 (5.37E−4)	1.22E−3 (4.64E−4)
Cylinders	2.51E−3 (1.62E−3)	−3.64E−3 (1.44E−3)	−3.72E−3 (1.59E−3)	−6.15E−4 (1.78E−3)	−2.57E−3 (1.45E−3)
Horsepower	5.59E−2 (1.87E−2)	5.29E−2 (1.83E−2)	6.74E−2 (1.91E−2)	6.09E−2 (2.04E−2)	5.60E−2 (2.01E−2)
Gals/mile	−3.18E−2 (4.74E−3)	−3.51E−2 (4.95E−3)	−3.01E+2 (4.11E−3)	−3.62E−2 (4.97E−3)	−3.35E−2 (5.01E−3)
Hardtop	−1.41E−1 (3.16E−2)	−1.28E−1 (3.11E−2)	−1.30E−1 (4.15E−2)	−7.55E−2 (2.99E−2)	8.27E−2 (3.41E−2)
Hatchback	−7.43E−2 (3.37E−2)	−2.75E−2 (3.04E−2)	−9.37E−2 (3.09E−2)	−8.74E−2 (3.69E−2)	−1.32E−2 (3.53E−2)
β_f				8.17E−5 (1.59E−3)	
β_j					8.86E−5 (5.25E−3)
σ_p^2	4.14E5 (2.38E4)	4.09E5 (2.11E4)	4.08E5 (2.29E4)	4.11E5 (2.16E4)	4.21E5 (2.03E4)
σ_q^2	4.66E7 (3.78E6)	4.71E7 (3.94E6)	4.60E7 (3.55E6)	4.74E7 (4.20E6)	4.77E7 (4.07E6)
σ_x^2	5.76 (6.21E−1)	5.64 (6.32E−1)	5.84 (6.14E−1)	5.88 (6.94E−1)	5.68 (7.09E−1)

Table 9
Alternative models of import distinctness — 1978.

	Model 1	Model 2	Model 3	Model 4	Model 5
E_u	1.97E5 (3.95E4)	1.99E5 (5.25E4)	2.05E5 (3.51E4)	2.02E5 (3.68E4)	2.08E5 (4.41E4)
E_u	4.22E1 (1.24E1)	4.70E1 (1.23E1)	3.91E1 (9.78)	4.18E1 (1.11E1)	4.26E1 (1.18E1)
E_l	2.01E3 (1.97E2)	2.81E3 (1.93E2)	2.39E3 (2.07E2)	2.40E3 (1.99E2)	2.36E2 (2.06E2)
γ_l	2.89 (2.04E−1)	2.55 (2.62E−1)	3.09 (2.03E−1)	2.92 (2.16E−1)	3.30 (1.75E−1)
δ	5.91E2 (5.14E1)	5.52E2 (4.10E1)	5.71E2 (4.69E1)	5.74E2 (6.30E1)	5.76E2 (5.94E1)
μ	1.56E2 (5.25E1)	1.61E2 (5.61E1)	1.50E2 (5.37E1)	1.41E2 (5.82E1)	1.80E2 (5.36E1)
μ_f		−4.183−1 (5.42E1)			
μ_j			−5.80E−1 (7.17E1)		
Constant	3.36E 3 (8.95E−4)	3.35E−3 (8.45E−4)	3.06E−3 (9.50E−4)	3.47E−3 (9.09E−4)	3.33E−3 (8.95E−4)
Length	1.20E−5 (2.66E−5)	1.15E−5 (2.64E−5)	1.43E−5 (2.68E−5)	1.21E−5 (2.62E−5)	1.12E−5 (2.80E−5)
Weight	6.14E−4 (3.87E−4)	5.82E−4 (4.58E−4)	6.21E−4 (3.98E−4)	5.76E−4 (3.91E−4)	6.42E−4 (3.83E−4)
Cylinders	−1.80E−3 (2.57E−3)	−1.73E−3 (2.56E−3)	−1.89E−3 (2.52E−3)	−1.89E−4 (2.67E−3)	−1.74E−3 (2.49E−3)
Horsepower	4.33E−2 (3.74E−2)	4.19E−2 (3.79E−2)	4.66E−2 (3.80E−2)	3.79E−2 (3.89E−2)	4.06E−2 (3.34E−2)
Gals/milc	3.22E 2 (1.07E−2)	−3.07E−2 (9.34E−3)	−3.12E−2 (1.08E−2)	−3.25E−2 (1.12E−2)	−2.96E−2 (1.09E−2)
Hard top	7.84E−2 (1.93E−2)	7.72E−2 (1.87E−2)	7.97E−2 (1.93E−2)	7.28E−2 (1.92E−2)	7.96E−2 (1.90E−2)
Hatchback	−1.09E−1 (2.53E−2)	−9.75E−2 (2.54E−2)	−1.09E−1 (2.57E−2)	−1.12E−1 (2.39E−2)	−1.12E−1 (2.37E−2)
β_f				8.17E−5 (1.59E−3)	
β_j					8.86E−5 (5.25E−3)
σ_p^2	5.52E5 (3.07E4)	5.51E5 (3.06E4)	5.59E5 (3.02E4)	5.45E5 (2.99E4)	5.58E5 (3.06E4)
σ_q^2	5.03E7 (4.09E6)	5.03E7 (4.06E6)	4.95E7 (4.11E6)	5.07E7 (4.06E6)	5.00E7 (4.17E6)
σ_x^2	4.48 (4.09E−1)	4.45 (4.04E−1)	4.49 (3.92E−1)	4.46 (3.91E−1)	4.52 (4.19E−1)

These new models can be described briefly. Model 1 is the one reported above. Models 2 and 3 have two alternative terms in the marginal cost function,

$$\begin{aligned} mc(t) &= \mu\, e^t, && \text{for domestic autos,} \\ mc(t) &= (\mu + \mu_f)\, e^t, && \text{for all foreign models (model 2),} \\ mc(t) &= (\mu + \mu_j)\, e^t, && \text{for all Japanese models (model 3).} \end{aligned} \tag{42}$$

Models 4 and 5 have a foreign (β_f) and a Japanese (β_j) dummy in the Z-vector, respectively.

The net effect of the attempt to find foreign differences can be stated simply. Foreign autos are not distinct from domestic. Neither the cost nor the quality parameters do anything in tables 8 and 9. Interpretation of this result is not obvious. On the cost side, perhaps the factor price equalization theorem is true after all. That consumers perceive foreign autos as identical, once their characteristics are correctly accounted for, is more surprising. Alternatively, this result can be interpreted as at least weak evidence that foreign competition has been in the form of fairly close substitutes in the late 70's. There is no evidence of significantly different behavior on the part of foreign producers. Thus foreign competition has exactly the expected welfare result. These findings are roughly consistent with those of Toder et al. (1978), who use a richer specification of preferences and costs, but assume perfect competition.

Appendix: Data

Automobile price, quantity and product characteristic data used in this paper come from two industry trade journals, Ward's and the Automotive News' annual Market Data Book. Prices are wholesale list prices, quantities, model year production. These figures have had to be approximated for many models. For all models, product characteristics were available as engineering data. The sample is defined to include only sedan, hardtop and hatchback models.

The definition of what constitutes a model is of central importance in the empirical work of this paper. When models differed only in trim (Deluxe vs. Luxury vs. Gran) and not in the engineering specifications, they were construed indentical. Their quantities were aggregated, and the price of the median among them was used. Disaggregated quantity data are usually not available for a breakdown by trim in any case.

All non-standard options are excluded from prices. List *retail* prices are from tables in both trade journals. For many models, wholesale prices can then be calculated using the Consumer Reports (1977–78) figures on dealer markups. For those models not reported in Consumer Reports, White's

(1968) piecewise linear dealer discount was used. This computes wholesale prices as a function of the retail price at the following discounts:

Full-sized: 75%, Compacts: 79%, Subcompacts: 83%.

Volkswagen prices are calculated this way, for example, since Volkswagen of America owns its dealers. The time and place specificity of prices is important. All are as of April 15th. Domestic producers' prices are f.o.b. Detroit, imports at entry. This supresses movements of price within the model year. Further, the tendency of small domestic models to sell cheaper west of the Rockies is ignored, as is the impact of transportation costs.

Quantity data are an area in which imports present a special problem. This paper uses the model (not the calendar) year as its time period. For domestic autos, model-run production is the natural quantity measure. For imports, October–September sales data are used. Monthly sales data are from Automotive News.

Engineering model specifications formed the quality proxies. The ones used are:

Overall length (inches),
Curb weight (pounds),
Number of engine cyclindes,[18]
Net horsepower,
Gallons per mile (EPA city estimate),[19]
Hatchback (1 if the model was this body type),
Hardtop (1 if the model was this body type).

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[18]Rotaries are construed to have 2.
[19]In these units because auto quality is assumed separable from money.

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