NBER WORKING PAPER SERIES

AUTOMOBILE PRICES AND QUALITY: DID THE GASOLINE PRICE INCREASE CHANGE CONSUMER TASTES IN THE U.S.?

Makoto Ohta

Zvi Griliches

Working Paper No. 1211

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 1983

Associate Professor, Institute of Socio-Economic Planning, The University of Tsukuba, and Professor of Economics, Harvard University, respectively. We are grateful to Professors E. Berndt, R. J. Gordon, F. Hayashi, Y. Kanemoto, D. McFadden, G. Ranis, K. Takoyama, H. Wago, and to Mrs. B. H. Hall and Mr. J. Kahn for their suggestions and encouragement. We also want to thank the National Science Foundation (SOC 78-04279) the Yoshida International Education Foundation and the NBER Productivity and Technical Change Studies Program for financial support. The research reported here is part of the NBER's research program in Productivity. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

NBER Working Paper #1211
October 1983

Automobile Prices and Quality: Did the Gasoline Price Increase Change Consumer Tastes in the U.S.?

ABSTRACT

Did the 1973 and 1979 gasoline price rises change consumer views about the relative quality of different cars? This question is investigated by testing the null hypothesis that imputed characteristic prices have remained constant over time. A hedonic model that takes gasoline costs into account is developed and some of its theoretical implications are outlined. The statistical methods required for its estimation and for the testing of the particular null hypothesis are discussed and then used to analyze the prices of U.S. passenger cars in the used market during 1970-1981. If one does not take gasoline costs into account in such computations one must conclude that consumers changed their relative evaluations of car qualities significantly in both periods: October 1973 to April 1974 and April to October 1979. However, when gasoline efficiency terms are included in the model, the estimated relative qualities are much more stable over time, with no period showing significant changes, and it is possible to maintain the "constancy of tastes" assumption. Since the main model adjusts not only for the effect of gasoline price increases but also for the effects of changes in other prices and income, we develop two alternative approaches which adjust solely for the increase in gasoline prices. Applying these to the 1979 period we find that a significant fraction of the coefficient change that did occur during this period can be attributed to the gasoline price increase alone, indicating that this is indeed a major component of what happened.

Makoto Ohta
Institute of Socio-Economic Planning
University of Tsukuba
Sakura, Ibaraki
305 Japan

Zvi Griliches
National Bureau of
Economic Research
1050 Massachusetts Ave.
Cambridge, MA 02138

I. Introduction

The energy crises of 1973 and 1979 and the associated increases in gasoline prices (see table 1) caused consumers to change their demand for automobiles and automotile manufacturers to adjust their products and prices to these changes. These events affected all the major dimensions of this market: (1) in the quantity dimension the market share of small cars increased relative to that of the large ones; (2) the price of small cars increased relative to that of large cars and the imputed characteristic prices (of weight, engine displacement, and gasoline miles per gallon) changed; and, (3) so did also the various automobile qualities: there occurred a downsizing in terms of length, weight, and horsepower, and an increase in gasoline efficiency.

While most analyses of these events start from the quantity dimension, looking usually at changes in quantities demanded or market shares [e.g. Carlson (1978), Greenlees (1979), Boyd and Mellman (1980)], a growing body of literature has recently taken the dual point of view and looked primarily at prices [Kahn (1981), Daly and Mayor (1983), Gordon (1983), Berndt (1983)]. We join this line of research but ask a somewhat different question, using a different model and different statistical methods.[1]

We use the hedonic hypothesis that automobile prices are a function of their characteristics, estimate the imputed prices of such characteristics and examine the effect of the gasoline price increases on them. Since the estimated quality of a car is the sum of the products of such imputed prices with their respective characteristic levels, we shall be analyzing how changes in gasoline prices affected the perceived qualities of different automobiles.

The used car market is our source of information. In the used car market quantities are fixed (more or less) and prices are determined primarily by consumer demand and can therefore be assumed to reflect current consumer tastes and price expectations. In contrast, new car prices are set by the manufacturers and need not be consistent, ex post, with the way consumers actually value the different models.

While one may think that consumers changed their notions of "quality," shifting their tastes towards smaller cars as the result of the two energy crises because small cars are more fuel efficient (as measured by miles per gallon which we abbreviate as MPG), this is not necessarily so. Because the amount of gasoline used does not enter the utility function directly but only through the budget constraint, it is possible that relative quality valuations did not change during the the energy crises once gasoline costs are accounted for appropriately.[2] The main purpose of this paper is to examine this possibility empirically.

If we define the <u>full</u> price of an automobile as the sum of its market price and the (gasoline) cost of operating it, we can restate the previous paragraph as follows: the energy crises may have increased the price of small cars relative to the price of large cars without changing much their relative <u>full</u> prices.[3]

Since imputed characteristics prices depend on consumer tastes (as well as on other factors), if we could show that correctly defined and measured these prices did not change, we could maintain the hypothesis that the underlying consumer preference structure did not change after all.

The hypothesis of no change in consumer taste is important for economic analysis, especially for comparative statics of consumer behavior. Hirshleifer (1976, p. 11) illustrates it by noting that when economists try to explain the effect of a tax on the demand for liquor, they "will almost automatically assume that the desire to drink is just as great (that is, preferences do not change by the imposition of tax) -- only that the tax makes it more expensive to indulge that desire (that is, tax (or higher price of liquor) affects budget constraint)." Economists cannot use their theoretical models and empirical estimates to explain the effects of such changes as the imposition of a tax or a gasoline price increase if consumer preferences change in an unknown manner. [4]

If the cost of gasoline is not taken into account, we expect to observe large changes in the imputed prices of automobile characteristics and in the estimated relative quality of different cars. We would like to know if these changes stopped soon after the oil price shocks were over. If this were the case, we could say that U.S. consumers adjusted their evaluation of quality differences rather quickly to the gasoline price increases.

The rest of the paper is organized as follows: First (section II) we outline our theoretical framework, restate the hedonic approach, and outline our estimation procedure. Next we describe our data (section III) and present our main empirical results (section IV). Brief conclusions (section V) close the paper.

II. Model, Implications and Statistical Method

The hedonic approach [Waugh (1928), Court (1939), Griliches (1961)] assumes that complex commodity prices are a function of their quality characteristics and estimates the imputed prices of such characteristics by regressing the prices of different commodity models on their characteristic levels. Muellbauer (1974), Lucas (1975) and Ohta (1980) show that the hedonic hypothesis can be based on Lancaster's (1971) consumer choice theory.

To make clear the distinction between characteristics that enter the utility function and those that enter only the budget constraint we start with a simple one-period model of consumer behavior. Suppose that there are only two kinds of goods, automobiles and other goods. Let $y = (y_1, y_2, \ldots, y_n)$ be a vector of automobile performance characteristics such as speed, roominess, comfort, handling, etc. Let $x = (x_1, x_2, \ldots, x_n)$ be a vector of physical characteristics such as weight, length, horsepower, etc. In general we expect y rather than x to enter the consumer's utility function. But since y can be thought of as a function of x (which is the two-stage hypothesis of Ohta-Griliches, 1976), and if this function is stable over the period of observation we can write the utility function as $u = u(x, K, z)$, where K is the number of miles driven and z is the quantity of other goods.

We assume that the consumer buys only one car and that he has to choose among a number of different car models. Then he is faced with the following maximization problem:

$$\max_{x, K, z, MPG} \quad u = u(x, K, z)$$

$$\text{subject to} \qquad P(x, MPG) + \frac{p_g \cdot K}{MPG} + p_z \cdot z = m$$

where $P(x, MPG)$ is the price of a car with characteristics $x = (x_i)$ and fuel efficiency (miles per gallon) MPG, p_g is the price of gasoline per gallon, p_z is the price of other goods and m is the consumer's income. $p_g \cdot K/MPG$ is then the gasoline cost of driving the car for K miles.[5]

Letting λ be a Lagrange multiplier, the first order conditions for this maximization problem are as follows:

$$\begin{aligned}
&u_{x_i} - \lambda P_{x_i} = 0 \quad (i = 1, 2, \ldots, n) \\
&u_K - \lambda p_g/MPG = 0 \\
&u_z - \lambda p_z = 0 \\
&P_{MPG} - p_g \cdot K/(MPG)^2 = 0 \\
&P(x, MPG) + p_g \cdot K/MPG + p_z \cdot z = m
\end{aligned} \tag{1}$$

where u_{x_i} equals $\partial u/\partial x_i$, P_{x_i} equals $\partial P(x, MPG)/\partial x_i$, etc. The number of variables is equal to the number of equations $(n + 4)$ and hence x, MPG, K can be solved for as functions of p_g, p_z, m and the functional form of $P(x, MPG)$.

The following quadratic approximation should be general enough for the hedonic price function $P(x, MPG)$:

$$P(x, MPG) = \sum_i \alpha_i' x_i + \beta(1/MPG) + \sum_i \sum_j \phi_{ij} x_i x_j + \phi(1/MPG)^2 + \sum_i \mu_i (1/MPG) x_i \tag{2}$$

where

$$\phi_{ij} = \phi_{ji} \quad .$$

Equations (1) and (2) give the following equation.

$$\begin{aligned} &\alpha_i' + 2\phi_{ii} x_i + \sum_{j \neq i} \phi_{ij} x_j + \mu_i (1/MPG) = p_z \cdot u_{x_i}/u_z \\ &\beta + 2\phi \cdot (1/MPG) + \sum_i \mu_i x_i = -p_g \cdot K \end{aligned} \tag{3}$$

Substituting (3) into (2), we obtain

$$P(x,MPG) = \sum_i \tilde{\alpha}_i x_i - p_g \cdot K/MPG - \sum_i \phi_{ii} x_i^2 - \phi(1/MPG)^2 - \sum_i \mu_i (1/MPG) x_i \tag{4}$$

where

$$\tilde{\alpha}_i = p_z \cdot u_{x_i}/u_z \quad .$$

To implement this model empirically we shall have to assume that all the square and cross-product terms vanish. We have tested this assumption partially and it is supported by the data for the square terms but not for the cross-product ones. Nevertheless, since we shall be analyzing the data as a system of equations, treating each half-yearly observation as a separate equation, we had to pare down our model further to make it operational. Hence we replace (2) by

$$P(x, MPG) = \Sigma\alpha_i' x_i + \beta/MPG \tag{5}$$

where from (3) $\alpha'_i = p_z \cdot u_{x_i}/u_z$

and $\beta = -p_g \cdot K$.

The imputed price of characteristic $i(\alpha_i)$ is its marginal utility in terms of the numeraire commodity z . Note that since the cost of gasoline enters only the budget constraint and not the utility function β does not depend directly on the utility function but only indirectly through K.

In market equilibrium α' and β are determined by demand for and supply of various models of used cars. Moreover, they will change over time to satisfy equation (5) which indicates that α' and β are related to p_g, p_z, x, z, K and the form of the utility function. Equation (1) indicates, in turn, that x, z and K are functions of p_g, p_z, m and the form of $P(x, MPG)$. So, α' and β depend on p_g, p_z, m and on consumer tastes.

If tastes change then the relative values of α's should change. One of the purposes of this paper is to test the null hypothesis of the constancy of the relative values of the α's. But even if this hypothesis is rejected, this does not necessarily imply that consumers tastes did in fact change, since the α's depend not only on the form of the utility function but also on the level of x.

Looking at (5) we see that the market price of a car is equal to its benefit minus cost, where benefit is the money value of the services it produces ($\sum_i \alpha_i' x_i$) and cost is the cost of operation (in this case just the cost of gasoline $p_g \cdot K/MPG$).

Equation (5) can be rewritten as

$$P(x, MPG) + p_g \cdot K/MPG = \sum_i \alpha_i' x_i \tag{6}$$

The left hand side is the sum of the market price of a car and the gasoline cost of operating it. Following the terminology of household production theory (Becker, 1965), this sum is interpreted as the <u>full</u> price of the car. The above equation shows that the full price of a car can be estimated by a weighted sum of its characteristics (excluding MPG), and is equal to its estimated "quality."

When quality-adjusted consumer price indexes for a commodity are constructed using the "price-link" method, it is common to assume that the market price ratio of goods is equal to their quality ratio. Equation (6) shows that this is wrong. The quality ratio (the ratio of the $\Sigma\alpha_i' x_i$'s) is not equal to the ratio of market prices (ratio of $P(x, MPG)$ for different models) but rather to the full price ratio (ratio of $P(x,MPG) + p_g \cdot K/MPG$).

To define the true quality adjusted price index note that the imputed absolute characteristic prices of α_i' can be rewritten as $\alpha_i' = u_{x_i} p_z/u_z = \alpha_i \overline{P}$, where α_i is now the relative marginal utility of characteristic i, and $\overline{P}$ is the quality adjusted price level (in terms of the numeraire commodity z) to which all these marginal utilities have to be equated. Denoting the gasoline cost component by g, equation (5) can be reparameterized

$$P(x, MPG) = \overline{P} \Sigma \alpha_i x_i - g \tag{7}$$

where $\overline{P}$ can be interpreted as the quality adjusted full price index. When we come to actual estimation we shall have to parameterize g further as will be explained below.

To see the implication of our null hypothesis about the constancy of the characteristics prices (α_i) we digress further: suppose the price of gasoline (p_g) changes. Let us denote the change in values of the various variables after the gasoline price change by Δ. Then, the null hypothesis implies that

$$\Delta P = \Delta\overline{P} \ \Sigma \alpha_i x_i - \Delta g \tag{8}$$

where $\Delta P = \Delta P(x, MPG)$. Comparing the resulting relative price change for two different models, h and k, we get

$$\frac{\Delta P_h/P_h}{\Delta P_k/P_k} = \frac{P_k}{P_h} \cdot \frac{\Delta\bar{P}\ \Sigma\alpha x(h) - \Delta g(h)}{\Delta\bar{P}\ \Sigma\alpha x(k) - \Delta g(k)} \tag{9}$$

indicating that since Δg is likely to differ for different cars the relative price structure of different car models will change as the result of the gasoline price change even without any changes in consumer tastes (that is, no change in the α_i's).

When oil prices increase, it will generally be the case that $\Delta g > 0$ and $\Delta\bar{F} > 0$, where the latter happens because of the inter-industry input-output relationships and the increase in energy cost. Then the first term in the right hand side of equation (8) is positive while the second term is negative and it is possible that the energy crisis can increase the prices of some cars (typically compact cars) in absolute value while decreasing the prices of other cars (typically full sized cars).

If there is no change in the true "full" price index $(\Delta\bar{P} = 0)$, equation (8) reduces to

$$\Delta P = -\Delta g \tag{10}$$

and the prices of all cars decline, including the price of compact cars.

Furthermore, if there is no change in miles driven (K), in spite of the increase in the price of gasoline, then (10) becomes

$$\Delta P = -\ g\ \Delta p_g/p_g \tag{11}$$

and the prices of all models decline proportionately to the rate of increase in the price of gasoline but the constant of proportionality, g, is different for different models and hence cars with a high gasoline cost-price ratio (g/P) will show larger price declines than those with small gasoline cost-price ratios.

Returning to the formulation of the regression model and remembering that automobiles are durable goods, we have to extend it to the multi-period context. Let $P_{tv}(x, MPG)$ be the price of a car of vintage v at time t with characteristics x and fuel efficiency MPG when new. The age of this car at time t is $s = t - v$. Characteristics x and MPG deteriorate with age s and so we write $x(s)$ and $MPG(s)$ to express this clearly. Since p_g, p_z, m and the form of $P_{tv}(x,MPG)$ may change over time, α_i and K depend on time, we write $\alpha_i(t)$ and $K(t)$ to denote this dependency. We denote the length of life of a car by T. As Manski (1980) has shown, T is a consumer decision variable (scrappage rate in his case) and will depend on t.

Following Hall (1971) and Kahn (1980), we write automobile prices as the discounted sum of their net rental values over time. Denoting the interest rate by r, we rewrite (5) as

$$P_{tv}(x, MPG) = \sum_{k=0}^{T(t)-t+v} \frac{1}{(1+r)^k} \left(\sum_i \alpha_i'(k+t)x_i(k+t-v) - \frac{p_g(k+t)\cdot K(k+t)}{MPG(k+t-v)}\right) \qquad (12)$$

where the one-period model P has been reinterpreted as the annual net rental and $\alpha_i'(k+t)$ is the imputed price of characteristic i at time $k+t$

expected by consumers at time t. Consumers calculate this expected value by using the optimization rule (1) and the expected values of their income and of all other prices. Assuming myopic expectations that future relative imputed characteristic prices are expected to be constant and equal to the present, we can write $\alpha_i'(k+t) = \tilde{P}(k+t)\alpha_i(t)$, where $\tilde{P}(k+t)$ is the absolute price level free of quality change at time $k+t$ and $\alpha_i(t)$'s represent relative price ratios of characteristics at time t. We write $\tilde{P}(k+t) = \overline{P}_t \cdot \Gamma_1(k)$ where $\Gamma_1(0) = 1$. Then $\overline{P}_t$ is interpreted as the quality-adjusted full price level of cars and $\Gamma_1(k)$ is interpreted as the expected rate of price inflation. Thus, we have the following.

$$\alpha_i'(k+t) = \overline{P}_t\ \alpha_i(t)\ \Gamma_1(k) \tag{13}$$

Similarly, we write $p_g(k+t)$ and $K(k+t)$ as follows

$$\begin{aligned} p_g(k+t) &= p_g(t)\cdot \Gamma_2(k) \\ K(k+t) &= K(t)\cdot \Gamma_3(k) \end{aligned} \tag{14}$$

$\Gamma_2(k)$ represents the expected rate of gasoline price inflation, and $\Gamma_3(k)$ is the increase in mileage driven in $k+t$ expected at t.

We assume a deterioration pattern of characteristics which allows us to write $x_i(k+t-v) = x_i \cdot \phi(k+t-v)$ for all i. This assumes the same rate of deterioration across all characteristics and car models. Similarly, we write $MPG(k+t-v) = MPG/\psi(k+t-v)$. These deterioration assumptions and the assumptions about expectations (13) and (14) allow us to write (12) as follows:

$$P_{tv}(x,MPG) = \overline{P}_t \cdot \phi(s) \cdot \sum_i \alpha_i(t) \cdot x_i - \Psi(s) \cdot p_g(t) \cdot K(t)/MPG \tag{15}$$

where $s = t - v$ (the age of the car) and $\phi(s)$ and $\Psi(s)$ are defined as follows:

$$\begin{aligned} \phi(s) &= \sum_{k=0}^{T-t+v} \phi(k + t - v) \cdot \Gamma_1(k)/(1 + r)^k \\ \Psi(s) &= \sum_{k=0}^{T-t+v} \psi(k + t - v) \cdot \Gamma_2(k) \cdot \Gamma_3(k)/(1 + r)^k \end{aligned} \tag{16}$$

$\phi(s)$ is the index of depreciation of all the characteristics except MPG at age s and $\Psi(s)$ is the comparable MPG depreciation index. These depreciation indexes are influenced by $\Gamma_1(k)$, $\Gamma_2(k)$ and $\Gamma_3(k)$ which are assumed to be the same across all models.

Equations (15) and (16) show that changes in the price of an automobile depend on many things: changes in the quality-adjusted price index $\overline{P}_t$, the economic life time of a car T which affects the depreciation terms $\phi(s)$ and $\Psi(s)$, the relative imputed prices α, the level of characteristics x and of MPG when new, the expected mileage K, the current price of gasoline and the expectations about the future course of its price

Letting $g(1/MPG, s:t) = \Psi(s)p_g(t)K(t)/MPG$, we can rewrite (15) as

$$P_{tv}\cdot(1 + g(1/MPG,\ s:t)/P_{tv}) = \overline{P}(t)\Phi(s) \sum_i \alpha_i(t)\ x_i$$

Taking logarithms of both sides we get

$$\log P_{tv} = \log \overline{P}_t + \log \Phi(s) + \log(\sum_i \alpha_i(t)\cdot x_i) - \log(1 + \frac{1}{P_{tv}}\, g(\frac{1}{MPG}\ ,\ s:t))$$

We now introduce a number of additional simplifying assumptions and approximations. First, we approximate

$$-\log\ [1 + \frac{1}{P_{tv}}\, g(\ \frac{1}{MPG}\ ,\ s:t)] \simeq\ -\ g(\cdot)/P_{tv}\quad .$$

Second, we approximate $g(\cdot)$ by

$$g(1/MPG,\ s:t)\ \simeq\ \beta(t)/MPG + \gamma(t)\cdot s + \varepsilon(t)\cdot s/MPG$$

and note that the parameters β, γ, and ε all depend on gasoline prices, among other things, and hence cannot be assumed constant over time.

Next, since we wish to use the semi-logarithmic form for the hedonic function, both because of considerations of superior fit and because of trying to preserve comparability with the earlier literature, we approximate $\log \Sigma\alpha_i(t)x_i$ by expanding it around $Q = \Sigma\alpha_i(t)\overline{x}_i$, the average "quality" level in year t, writing

$$\log \Sigma\alpha_i x_i =\ \log\ [\Sigma\alpha_i(x_i - \overline{x}) + Q]\ = \log[Q(1+\Sigma\frac{\alpha_i}{Q}(x_i-\overline{x}))]$$

$$= \log Q + \log \left[1 + \Sigma \frac{\alpha i}{Q} (x_i - \bar{x})\right]$$

$$\approx \log Q - 1 + \Sigma \alpha_i' x_i$$

where $\alpha_i'(t) = \alpha_i(t)/Q(t)$ is now the relative characteristic price per unit of "average" quality in year t.[6] Since we are interested only in comparing α_i to α_j, in discussing possible changes in the <u>relative</u> prices of characteristics, this redefinition does not matter. For typographical simplicity, we shall drop the distinction between $\alpha' = \alpha/Q$ and α, but it should be noted that the meaning of these coefficients is now somewhat different. (We shall ignore the $Q(t)$ term, as it will be subsumed in the year dummies that we shall add to each cross-section). Using dummy variables to estimate the hedonic price index $\overline{P}_t$ and depreciation term $\Phi(s)$, equation (12) can be then rewritten as follows:

$$\log P_{tv}(x, MPG) = \sum_k \pi_k T_k + \sum_s \delta_s D_s + \sum_i \alpha_i(t) x_i - [(\beta(t)/MPG + \gamma(t)\cdot s + \varepsilon(t)\cdot s/MPG)]/P_{tv} \tag{17}$$

and where T_k and D_s are variables referring to period k and age

$s = t - v$ respectively.

As noted before, one of the main purposes of this paper is to test the constancy of the α_i's over time in equation (17).[7] We allow β, γ and ε to change over time in such tests, because they reflect also the overall levels of gasoline, automobile, and other prices and income. The age coefficients δ_s are also allowed to change over time because deterioration patterns may have changed for different vintages.

There are several econometric issues which arise in trying to estimate (17) and its various variants. First, P appears also on the right hand side of the equation, as a divisor of the gasoline cost component. We solve this problem by using a three-stage procedure: First the log P equation is estimated based on the x's (characteristics) alone, yielding a $\hat{P}$ to be used in stage 2 to estimate equation (17). This yields a new $\hat{P}$, which is used in the final third stage to reestimate (17).[8]

Since the β, γ, and ε parameters in (17) depend on many other things besides gasoline prices, we would like to ask whether the changes that occurred in the coefficients are due primarily to changes in gasoline prices (or more correctly, to changes in the evaluation of fuel efficiency). One way of doing this is to use equation (5) to predict car prices in time $t + 1$ from the estimated coefficients in time t (denoting them as α_{it} and $\hat{\beta}_t$) and the rate of gasoline price increase between t and $t + 1$ (denoting it as σ). If the gasoline price changes are the main cause of the changes in the coefficients then $\Sigma\hat{\alpha}_{it}x_i + (1 + \sigma)\hat{\beta}_t/MPG$ should predict car prices at $t + 1$ well up to a constant. We call this the "prediction method."

The other way of doing this is to consider the misspecified version of (17), in which the gasoline terms are excluded, say $\log P = \Sigma\rho_i x_i$, while the true equation is $\Sigma\alpha_i x_i - g/M$, where we have dropped the various year and age dummy variable terms to simplify the exposition, $g = p_g K/P(x,\mathrm{MPG})$, and $M = \mathrm{MPG}$. Consider the linear projection (auxiliary equation) of $1/M$ on x: $1/M = \Sigma\mu_i x_i$; then, by the well known omitted variables argument[9] we can write

$$\rho_i = \alpha_i - g\mu_i \quad .$$

Suppose gasoline prices increase by σ percent, holding other things constant. Then g is also increased by σ percent. Letting $\tilde{\rho}_i$ be the value of ρ_i after this increase yields

$$\tilde{\rho}_i = \alpha_i - (1 + \sigma)g\,\mu_i = \rho_i - \sigma g\,\mu_i \quad .$$

We can examine, therefore, the effects of gasoline price increases isolated from other changes by estimating unconstrained and constrained versions of (17), without the gasoline consumption terms, and ask whether the estimated ρ parameters satisfy the constraints implied by the $\tilde{\rho}$ formula. In both versions $P(x, \mathrm{MPG})$ is the price <u>after</u> the gasoline price increase. If the SER of the constrained regression is not much larger than that of the unconstrained, then changes in the imputed prices of automobile characteristics can be explained mostly by the gasoline price increases. Other factors, such as general price level and income, do not affect the imputed prices much.

We use the SUR (seemingly unrelated regressions) procedure in estimating the various versions of (17). Since it is likely that our list of characteristics is incomplete and since we have omitted the cross terms of 1/MPG and x we expect a non-negligible correlation between different year but same model residuals. The observed correlation is close to 0.9. Another way to reduce the effect of omitted characteristics would be to use dummy variables for the different car makes. But even if we use such make dummies, the correlation coefficient is still high (around 0.7). We use, therefore, the SUR procedure which does take into account this kind of correlation in evaluating the precision of our estimates.

The usual F-statistic for testing hypotheses in such frameworks [the SUR version is given in Theil (1971), equation (3.6) on pp. 314] has the following shortcoming, as Leamer (1978) points out: When the number of observations is large, the computed F-value tends to be large, the critical F-level is small[10], and the null hypothesis is almost always rejected. (Our sample sizes are around 500.) This makes little sense and hence several alternative testing approaches have been suggested in the literature.

Leamer derives a Bayesian critical level L_B under the assumption of diffuseness of prior information. We will use this critical level in our F-tests:

$$L_B = (n - k)\cdot(n^{q/n} - 1)/q$$

Here k is the number of parameters in the unconstrained regression and q is the number of parameters to be constrained by the null hypothesis.

In addidition, when testing the null hypothesis we shall look not only at the F-value but also look at the estimated standard error of regression (abbreviated as SER). Following Arrow (1960) and Ohta-Griliches (1976), we judge the practical significance of the null hypothesis by comparing the difference in SER between the constrained and the unconstrained regressions. If the difference in SER (abbreviated as ΔSER) is smaller than .010 in the system under the test, we do not reject the null hypothesis practically. Since the left hand variable is the logarithm of price, an increase in SER by .010 implies an increase in the standard deviation of the unexplained component of price of about 1 percent. Since SER in our regression is around .2, the .010 criterion implies that we are willing to accept up to a 5.0 percent deterioration in fit. We call this test the ΔSER test. We use the SER of OLS rather than the SUR one in this test because we are interested in the decrease in "fit" due to the imposition of the null hypothesis and because OLS minimizes the actual sum of squared residuals while the SUR method does not do so, minimizing instead a transformed version of it.

The ΔSER test can be thought of as examining whether the imposition of the null hypothesis of relative constancy of imputed characteristic prices makes a substantive difference to our estimates of the overall "quality" of different cars. Letting $x_k = (x_{ik})$ be the vector of characteristics of car model k and $\alpha_t = (\alpha_{it})$ the vector of imputed prices of characteristics at time t, then $\hat{\alpha}_t \cdot x_a / \hat{\alpha}_t \cdot x_b$ (that is, the ratio of the fitted values) is the estimated relative quality of model a, relative to model b, at time t. Since the left hand variable is the logarithm of price, ΔSER measures the difference in fitted values (that is, in relative estimated qualities) caused by the imposition of the null hypothesis.

Since consumers buy a bundle of characteristics x embodied in a particular car rather than specific amounts of one or other characteristic, changes in the overall quality $\alpha \cdot x$ may be of more interest than changes in the individual price ratios. If the ratios of the imputed prices are constant over time, then relative qualities of different models do not change. Even if there is a change in the imputed prices, relative qualities may still not change. This can happen because characteristics are highly collinear. For example, if $x_a = (1, 2)$ and $x_b = (2, 4)$ are the characteristic vectors of models a and b respectively, the relative quality of model b is two irrespective of imputed prices. Thus, significant changes in relative imputed prices of characteristics need not imply significant changes in the relative quality evaluations of different cars.

III. Data

Our data on U.S. domestic passenger car prices and characteristics are taken from N.A.D.A. Official Used Car Guide. We collected the characteristics of 1966 to 1980 vintage cars and their prices in the used car market biannually (October and April) from 1970 to 1981A. In these data six years is the oldest age that we observe. We do not use the October prices of new vintages in our study of the used market, because transactions in these cars are not numerous enough to make their prices a reliable reflection of consumer evaluations.[11]

The earlier Ohta-Griliches data set contained only sedans and hardtops with four or two doors. The new data collected for the 1970-80 vintages include also station wagons and coupes with four, two, three, and five doors, encompassing all segments of the passenger car market.

The following physical characteristics were used by us: (1) number of cylinders, (2) shipping weight (in pounds), (3) number of doors, (4) wheelbase (in inches), (5) length (inches), (6) width (inches), (7) CID (cubic inch displacement of engine), (8) brake horsepower, (9) AT (dummy for automatic transmission, 1 if standard, 0 otherwise), (10) PS (dummy for power steering, 1 if standard, 0 otherwise), (11) AC (dummy for airconditioning, 1 if standard, 0 otherwise).

MPG data are taken from E.P.A. publications, but these are available only for 1974 and later vintages. Furthermore, they are for city driving in some years and for highway or combined city and highway driving in other years. (This is indicated in Appendix Table A2.) We can match our sample cars perfectly with the cars in E.P.A. publications after 1975. In 1974, the match is imperfect and we use occasionally the MPG data for the nearest available similar car (nearest in CID and weight within the same make).

We used Facts and Figures of Consumer Reports to get the MPG data for 1966-73 vintage cars. For 1966 vintage cars, we use traffic gas mileage data, which involve acceleration, 35 mph maximum, idling, and an average speed for the course of about 21 mph. For 1967-73 vintage cars, we use the arithmetic average of the upper and lower extremes of the range of gas mileage to be expected in normal use. The upper extreme is for short-range stop-and-go traffic and the high extreme is for open-road, constant-speed trips. Thus, the Consumer Reports MPG data correspond roughly to city MPG data of E.P.A. although we do not use both data simultaneously. The number of models for which Consumer Reports MPG data are available is rather small (see Table A3).

IV Empirical Results

The impact of the oil-price rises on the used car market is our primary interest. We hope to show that these events affected this market in an intelligible way. We shall do this first by estimating more or less standard hedonic price equations for used cars and showing that their coefficients changed over time, especially during the two major gasoline price rise episodes (1973-74 and 1979-80). Second, we add fuel consumption efficiency variables to these equations and show that the coefficients of the remaining characteristics are now much more stable over time. Finally, we examine if the changes observed in the first set of results can be accounted for by the changes that occurred in gasoline prices. By and large, all these questions are answered affirmatively, indicating that this market (and the consumers that are active in it) responded as one might have predicted to changes in its economic environment, and did so quite rapidly.

The first set of calculations is based on comparing pairs of adjacent time period equations using the same set of vintages and models for the comparison. One set of equations is estimated unconstrained, allowing all the coefficients to differ across time periods, while the second set imposes the restriction that the coefficients of the various physical characteristics, the "imputed prices," are constant over time. Both versions are estimated using the SUR procedure which allows the residuals in these equations to be correlated over time, and the plausibility of the null hypothesis (the constrained version) is evaluated using Leamer's Bayesian version of the standard F-statistic and our own ΔSER test.

The physical characteristics used in these equations (in addition to time and age dummies) are: (1) CID, (2) number of cylinders (abbreviated as NOC), (3) weight (WT, in pounds), (4) wheelbase x width (WBW, in squared inches) (5) dummy for number of doors less than 4 (NOD2), (6) dummy for number of doors greater than 4 (NOD5), (7) AT, (8) PS and (9) AC. (1) and (2) contribute to speed, (3) and (4) mainly to roominess of a car, (5), (6), and (9) to the quality of the ride, and (7) and (8) to the ease of driving and maneuvering.

We tried a number of other variables and variants in preliminary analyses without affecting the final results significantly. For example, we tried using length and length times width in addition to the WBW variable and a WT/WBW variable, a proxy for the sturdiness of a car, instead of the WT variable, without any noticeable improvement in the results. Because the effect of H (horsepower) relative to CID appears to have declined over time, we have included them both in the early 70's equations. We also experimented with the inclusion of make dummies (thirteen domestic makes) to capture the effects of omitted characteristics. While the inclusion of make dummies did improve the fit, it did not change any of our testing conclusions. To reduce the computational burden we do not consider them further here.

Table 2 illustrates the types of equations estimated and the kinds of results obtained. It also shows two problems with these estimates: the estimated coefficient of the AC (air conditioning) dummy variable is too high. It implies that cars with air conditioning as standard equipment are on the average 40 percent more expensive. This is unrealistic and is probably due to the correlation of AC with some other unmeasured characteristics.[12] On the other hand, the coefficient of WBW (wheelbase times width), a proxy for size, is significantly negative. This too is probably due to its correlation with unmeasured characteristics and multicollinearity with some of the included ones, such as CID. Because we are interested in detecting substantial changes in the valuation of the set of characteristics as a whole, a single or even several wrong-signed coefficients do not invalidate our overall results.

Our first set of results is summarized in Table 3 which presents the various test statistics for the unconstrained and constrained adjacent period regressions while <u>excluding</u> the gasoline consumption terms. For such comparisons the conventional critical F-value is about 2.0-2.5 at the one percent significance level while the Bayesian critical level is between 6.2 (for $n = 330$, $K = 39$, and $q = 18$) and 6.9 (for $n = 1000$, $K = 26$, $q = 9$). Even using the more conservative Bayesian approach, the coefficients appear to be changing most of the time. But the impact of these changes on the overall fit of these equations is rather small. Only in 1973O-74A and 1974A -74O do the constraints cumulatively amount to about .01, and only in 1979A - 79O does the imposition of the constraint of constancy of coefficients "cost" more than .01 in terms of ΔSER.[13] Although not significant by our practical criterion, ΔSER adds up to .003 and the value of the F-statistic is large in 1977A - 77O and 1977O - 78A. Taking all these results together, we would have to conclude, having ignored considerations of gasoline efficiency in these comparisons, that consumers had changed their evaluation of physical characteristics significantly during this period, especially in 1973O - 74A and 1979A - 79O. These periods were, in fact, periods of rapid gasoline price rises. It is also interesting to note that these changes in relative evaluation occurred quickly and were over soon after the gasoline price rises had run their course. In this sense, it appears that consumers adjusted rather quickly.

So far we examined half-year periods (i.e., April - October comparison within a year) in order to discern when the estimated characteristics coefficients had changed significantly. In Table 3A we check also the stability of the estimated coefficients over longer time periods. While this is only a cursory check, because different vintages are used at different time points in the 1974O - 80A comparisons and because these are still only two-point comparisons, Table 3A tells the same story as Table 3. Except for the two oil shock periods, the estimated coefficients are stable by our ΔSER criterion. 1977A - 78A period shows some instability as in Table 3, but it is not significant.

We turn next to the estimation of price equations which allow for the changing cost of gasoline consumption. This is accomplished by adding to the previous equations the three following terms.

$$(\beta/MPG + \gamma \cdot Age + \varepsilon\ Age/MPG)/\hat{P}$$

where $\hat{P}$ is computed by the three-step iterative procedure described above.

Table 4 summarizes the results of such computations for the 1975-81 period, and Table 5 illustrates (for 1979A and O) the type of equation estimated and the results obtained.

Comparisons of Tables 3 and 4 show that the computed F-values and the ΔSERs fall drastically when we take the cost of gasoline into consideration. There are no substantively significant changes in imputed characteristic prices in any period by our ΔSER criterion, although the ΔSER is still .005 in 1979A-79O. Table 5 shows that the imputed price of body size (WBW and WT) decreased relative to that of engine size (CID). This change is the same as that observed without consideration of gasoline cost in Table 2. From the ex-post point of view consumers may have over-reacted to the second oil price shock in 1979.

To get comparable estimates for the earlier years of this period we had to resort to the much smaller Consumer Reports based sample. The results of these computations are summarized in Tables 6A and 6B. When the gasoline consumption terms are included there are no significant changes in any period in Table 6, either on the Bayesian or the ΔSER criterion.[14]

Thus, once the gasoline efficiency variables are added to the standard hedonic regressions, the hypothesis of constancy of relative imputed prices of the physical characteristics cannot be rejected for any of the half-year periods during 1970-81.

So far we tested the constancy of imputed prices, using the framework associated with equation (17). In (17) the parameters β, γ and ε depend not only on the price of gasoline but also on other factors such as automobile prices, the general price level and income. Our third approach to the problem attempts to examine the effect of gasoline price increases alone, holding the other factors constant. We will do this for our "worst fit" case, the 1979A - 790 period, following the methods described in Section II. The sample consists of 1974-77 vintage cars.

To use the "prediction" method we take the unconstrained estimates for 1979A (from Table 5) and use them to predict the 19790 prices. In these "predictions" we allow the overall period (price level) and vintage (age) coefficients to change and concentrate on the differential treatment of gasoline efficiency variables over time. More specifically we first form the "residual price" variable

$$LLP = \log\ [P_{19790}(x,\ MPG)] - (\Sigma\hat{\alpha}_{iA}x_i + G_A)$$

where

$$G_A = [\hat{\beta}_{1A}/MPG + \hat{\beta}_{2A}AGE + \hat{\beta}_{3A}\ AGE/MPG]/\hat{P}_{79A}$$

is the predicted gasoline cost component based on 1979A data and prices, and then regress it (LLP) on a constant and vintage dummies. The SER of this regression is .224. This is the most contrained version, one that assumes that none of the coefficients (except for the constant and vintage dummies) changed between 1979A and 19790.

In the next computation, we allow the G component to change in proportion to the estimated rise in the price of gasoline during this period, 29.7 percent (based on the gasoline price component of the CPI). Here, the regression of

$$LLPA = \log\ [P_{19790}\ (x, MPG)] - [\Sigma\hat{\alpha}_{iA}x_i + (1 + .297)G_A]$$

on a constant and vintage dummies yields an SER of .214.

Alternatively, we need not assume the expected rate of gasoline price inflation but can estimate it by regressing

$$LLPB = \log\ [P_{19790}\ (x, MPG)] - \Sigma\hat{\alpha}_{iA}x_i$$

on a constant, vintage dummies, and G_A. The resulting coefficient of G_A is 2.2 with a standard error of .12, significantly larger than the 1.3 implied by the actual gasoline price rise between 1979A and 19790, implying that some non-negligable fraction of this inflation rate was extrapolated (perhaps not unreasonably) into the future. The SER for this regression is .202.

The fully unconstrained regression for 19790, with all coefficients allowed to change has an SER of .177. Thus in terms of percentage change in the unexplained variance due to the imposition of the various constraints, out of the .0185 change in the residual variance between the constrained to 1979A coefficients and the unconstrained version, 24 percent can be explained by allowing the gasoline component to change in proportion to the actual inflation, and 51 percent if consumers are allowed to extrapolate some of this inflation into the future. Thus, a significant portion of the change in estimated coefficients during this period can indeed be associated with the changes in gasoline prices.[15]

We use next the omitted variable approach to look at the same thing from a different point of view and try to explain the changes that occur in the imputed prices of characteristics when gasoline cost variables are omitted from the regressions. First, we take the corresponding coefficients of the unconstrained regression for 1979A from Table 2 and use them to construct the "residual price" variable

$$LLP = \log\,[P_{19790j}] - \Sigma_i \hat{\rho}_{iA} x_{ij}$$

where $\hat{\rho}_{iA}$ are the estimated characteristics coefficients in the 1979A regression. We regress this variable on a constant and vintage dummies, which yields an SER of .228.

Now we calculate $\tilde{\rho}_i = \hat{\rho}_{iA} - \sigma g \mu_i$, where μ_i are the coefficients in the regression of 1/MPG on all of the included x characteristics (given in Table 7)[16], σ is the observed rate of gasoline price inflation .297, and $g = P_g \cdot K/P$ is set to 10.[17] Then, the alternative "residual price"

$$LLPA = \log P_{19790j} - \Sigma \tilde{\rho}_i x_{ij}$$

is calculated and regressed on a constant and vintage dummies, yielding an SER of .207.

Here too we need not assume that there was no extrapolation of the gasoline price rises into the future. Instead, we can iterate on σ in a search for the value that fits best. This occurs at about .9 (rather than .3), indicating a significant extrapolation of current gasoline price changes into future, and yields an SER of .191.

All of these estimates are to be compared to the unconstrained estimates for 1979O whose SER is .182. Thus, in terms of the difference in the unexplained variance of 1979O prices between the unconstrained and the 1979A coefficients version (.0189), 48 percent of it can be explained by allowing the characteristics coefficients to change in proportion to their relationship to the left out variable 1/MPG and the observed rise in gasoline prices (.297), and 82 percent if we use the higher rate of gasoline price inflation extrapolation implied by the data.

For reasons not entirely clear to us, the simpler omitted variable approach, which focuses on only one variable (1/MPG), gives a greater role to the gasoline price changes in accounting for the changes that occurred in the hedonic price equations between 1979A and 1979O, than the more complete three-variable "prediction" approach. Both methods yield roughly similar results, however, with the gasoline price change accounting for between one quarter to three quarters of the observed change, depending primarily on whether we allow for an extrapolation of the gasoline price rises into the future or not.

V. Conclusions

The purpose of this paper was to ask whether U.S. consumers changed significantly their views about the relative qualities of different cars in the face of the 1973 and 1979 gasoline price rises. This was done by testing the null hypothesis that imputed characteristics prices have remained constant over time. To accomplish this we first outlined a hedonic model that takes gasoline costs into account, pointed out some of its theoretical implications, and discussed the statistical methods required for its estimation and for the testing of the particular null hypothesis. The model and the estimation methods were then used to analyze the prices of U.S. passenger cars in the used market during the 1970A - 81A period.

Our main findings are:

(a) If one does not take gasoline costs into account then one would have to conclude that consumers changed their relative evaluations of car qualities significantly in 1973O-74A, and 1979A-79O. They were very quick, however, in adjusting these evaluations to the oil-price shocks.

(b) When we do take gasoline costs into account, the estimated relative qualities become much more stable over time and there is no period that shows a significant change. In this form it is much easier to maintain the "constancy of tastes" assumption.

(c) Our main model adjusts not only for the effect of gasoline price increases but also for the effects of other changes such as changes in other prices and income. We developed models which adjust solely for the increase in gasoline prices. Applying these models to the 1979A-79O period we observed that between one and three quarters of the decrease in the unexplained variance of 1979O prices which arose from allowing characteristics coefficients to change from those anticipated in 1979A can be explained by the increase in gasoline prices alone, indicating that this is indeed a major component of what did happen.

Table 1: Consumer Price Index (CPI) components: 1969-1981

Year·month*		(1) All items	(2) Gasoline (Regular and premium)	(3) New car	(4) Used car	(5) Real price of gasoline (2)/(1)	(6) Relative price of used cars (4)/(3)
69	A	108.7	105.3	107.1	107.6	97	100
	O	111.6	105.9	109.5	103.2	95	94
70	A	115.2	106.6	109.6	99.3	93	91
	O	118.1	106.7	114.2	106.8	90	94
71	A	120.2	103.7	113.8	109.8	86	96
	O	122.6	108.8	115.3	111.7	89	97
72	A	124.3	105.0	111.7	106.4	84	95
	O	126.2	110.2	110.1	115.2	87	105
73	A	130.7	113.8	111.1	117.3	87	106
	O	136.6	121.8	111.9	118.5	89	106
74	A	144.0	161.4	113.3	110.7	112	98
	O	153.2	160.9	123.7	152.3	105	123
75	A	158.6	162.8	127.5	138.1	103	108
	O	164.6	178.7	129.9	156.5	109	120
76	A	168.2	171.2	134.4	159.4	102	119
	O	173.3	179.9	139.1	179.9	104	129
77	A	179.6	187.0	140.6	187.8	104	134
	O	184.5	190.0	145.7	178.0	103	122
78	A	191.5	190.1	151.2	177.3	99	117
	O	200.9	202.0	155.1	195.4	101	126
79	A	211.5	235.4	163.9	200.0	111	122
	O	225.4	305.2	167.4	199.9	135	119
80	A	242.5	376.3	177.7	196.8	155	111
	O	253.9	371.7	182.0	222.7	146	122
81	A	266.8	420.8	186.2	239.1	158	128

*Note: A denotes April and O denotes October. From U.S. Bureau of Labor Statistics, The Consumer Price Index.

Table 2: Imputed prices of physical characteristics, selected years.

Physical characteristics	Estimated coefficients					
	1973O	1974A	1977O	1978A	1979A	1979O
CID[1]	.194 (6.226)	.223 (6.609)	.249 (9.008)	.245 (7.828)	.174 (5.695)	.167 (5.766)
NOC	-.039 (-2.675)	-.059 (-3.705)	-.036 (-2.644)	-.032 (-2.065)	.011 (.737)	.001 (.058)
WT[2]	.284 (5.720)	.187 (3.480)	.009 (.456)	.019 (.797)	-.002 (-.067)	-.006 (-.261)
WBW[3]	-.233 (-10.745)	-.278 (-11.834)	-.070 (-4.260)	-.119 (-6.401)	-.084 (-4.655)	-.176 (-10.289)
NOD2	.092 (4.590)	.062 (2.887)	.070 (3.222)	.063 (2.589)	.071 (3.029)	.052 (2.349)
NOD5	-.006 (-.176)	.012 (.345)	-.024 (-.851)	-.054 (-1.670)	-.016 (-.521)	-.051 (-1.725)
AT	.110 (2.554)	.056 (1.193)	-.084 (-2.511)	-.118 (-3.125)	-.101 (-2.901)	-.120 (-3.606)
PS	.150 (3.501)	.161 (3.454)	.179 (5.502)	.215 (5.840)	.291 (8.496)	.274 (8.423)
AC			.386 (9.225)	.383 (8.079)	.449 (10.040)	.474 (11.128)
Vintage used	70-72	70-72	74-76	74-76	74-77	74-77
No. of obs.	369	369	351	351	473	473
SER	.142	.154	.152	.172	.192	.182
R^2	.846	.796	.800	.751	.773	.776

Note: The reported regressions include also a constant and vintage dummies besides the above characteristics.
R^2 is the multiple correlation coefficient squared.
T-value is in parenthesis.

1. In 100 cubic inches 2. In 1000 pounds 3. In 1000 square inches

Table 3: Tests of equality of imputed prices of physical characteristics over time in regressions which exclude the gasoline efficiency variables.

Year·month compared	Vintage of cars used	Estimated F-statistic (SUR)	Degrees of freedom for the F-statistic	SER Unconst. OLS	SER Constrained OLS
1970A, 71A	1966-69	7.31	7, 476	.123	.123
71A, 72A	70	7.25	8, 234	.124	.123
72A, 720	70	4.45	8, 234	.121	.120
720, 73A	70,71	12.56	8, 480	.132	.132
73A, 730	70,71	7.09	8, 480	.142	.142
730, 74A	70-72	90.35	8, 716	.148	.156
74A, 740	70-72	28.67	8, 716	.151	.153
740, 75A	70-73	13.54	8, 940	.150	.150
75A, 750	70-73	11.45	8, 940	.158	.158
750, 76A	74	2.44	9, 202	.129	.127
76A, 760	74	7.53	9, 202	.143	.142
760, 77A	74,75	1.27	9, 434	.156	.155
77A, 770	74,75	12.70	9, 434	.163	.164
770, 78A	74-76	45.37	9, 678	.162	.164
78A, 780	74-76	9.79	9, 678	.175	.175
780, 79A	74-77	6.20	9, 920	.184	.183
79A, 790	74-77	242.25	9, 920	.187	.199
790, 80A	74-78	41.73	9, 1190	.188	.189
80A, 800	74-78	17.49	9, 1190	.201	.201
800, 81A	76-79	24.55	9, 1024	.167	.167

Note: (1) Regression equation system is equation (17) of the text without the MPG terms.

(2) SER -- Standard error of regression. Unconstrained SER is also for SUR estimates as well as OLS.

Table 3A: A cursory look at the change in imputed prices over longer periods.

Year·month compared	Vintage used	SER	
		Unconst. OLS	Constrained OLS
71A, 740	70	.139	.164
71A, 730	70	.140	.148
720, 740	70-71	.136	.152
720, 730	70-71	.131	.135
740, 80A	70-72*, 75-77**	.162	.173
740, 790	70-72 , 75-77	.155	.164
740, 79A	70-72 , 75-77	.163	.169
740, 77A	71-73	.158	.161
77A, 78A	72-75	.187	.194
78A, 79A	75-76	.172	.171
79A, 81A	75-78	.181	.214
790, 81A	75-78	.177	.182

Note: * -- vintages used for the first month.

** -- for the second month in the comparison.

Table 4: Tests of equality of imputed prices of physical characteristics over time allowing for changes in the evaluation of gasoline efficiency.

Year.month compared	Vintage of cars used	Estimated F-statistic (SUR)	Degrees of freedom for the F-stat.	SER Unconstrained OLS	SER Constrained OLS
750, 76A	74	.00	9, 196	.122	.120
76A, 760	74	.60	9, 196	.137	.135
760, 77A	74,75	.54	9, 426	.156	.154
77A, 770	74,75	1.77	9, 426	.162	.162
770, 78A	74-76	6.21	9, 660	.160	.159
78A, 780	74-76	2.44	9, 660	.172	.171
780, 79A	74-77	2.64	9, 912	.179	.179
79A, 790	74-77	12.21	9, 912	.182	.187
790, 80A	74-78	6.41	9, 1180	.183	.182
80A, 800	74-78	3.33	9, 1180	.193	.192
800, 81A	76-79	6.26	9, 1014	.160	.159

Note: Text equation (17).

Table 5: Imputed prices of characteristics in 1979A-19790 (with gasoline efficiency terms included).

Characteristics	1979A Estimated coefficient	1979A t-value	19790 Estimated coefficient	19790 t-value
CID	.253 E-2	6.301	.213 E-2	5.482
NOC	.120 E-1	.818	.300 E-2	.212
WT	.103 E-4	.457	.554 E-6	.026
WBW	-.108 E-3	-4.505	-.177 E-3	-6.164
NOD2	.757 E-1	3.104	.441 E-1	1.984
NOD5	-.154 E-1	-.501	-.352 E-1	-1.192
AT	-.971 E-1	-2.637	-.910 E-1	-2.651
PS	.333	6.270	.262	5.669
AC	.444	7.340	.412	7.336
$1/(MPG\cdot\hat{\hat{P}})$	-6546	-.740	-10237	-1.506
Age of Car/$\hat{P}$	254	3.291	114	1.959
Age of Car/$(MPG\cdot\hat{\hat{P}})$	-163	-.088	563	.435
Vintage used	74-77		74-77	
No. of obs.	472		472	
SER	.187		.178	
R^2	.785		.789	

Note: These regressions contain also a constant and vintage dummies besides the above characteristics. The estimated F-statistic of $1/(MPG\cdot\hat{\hat{P}})$, Age/$\hat{\hat{P}}$ and Age/$(MPG\cdot\hat{\hat{P}})$ is 8.75 for 1979A and is 9.25 for 19790, with 3 and 456 degrees of freedom.

Table 6A: Test of equality of imputed prices of physical characteristics over time excluding gasoline efficiency variables (Consumer Reports sample)

Year·month compared	Vintage of cars used	Estimated F-statistic (SUR)	Degrees of freedom for the F-statistic	SER Unconst. OLS	SER Constrained OLS
1970A, 71A	66-69	1.09	6, 148	.111	.109
71A, 72A, 720	70	3.07	14, 33	.083	.082
720, 730	67-71	6.35	6, 192	.176	.176
730, 74A	70-72	10.59	8, 98	.143	.152
74A, 740	70-72	9.30	8, 98	.152	.154
740, 75A	70-73	1.09	8, 150	.136	.133
75A, 750	70-73	2.16	8, 150	.146	.143

Table 6B: Test of equality of imputed prices of physical characteristics over time allowing for changes in the evaluation of gasoline efficiency (Consumer Reports sample)

Year.month compared	Vintage of cars used	Estimated F-statistic (SUR)	Degrees of freedom for the F-statistic	SER Unconst. OLS	SER Constrained OLS
1970A, 71A	66-69	.98	6, 142	.110	.109
71A, 72A, 720	70	.93	14, 24	.090	.080
720, 730	67-71	2.28	6, 186	.176	.176
730, 74A	70-72	1.58	8, 92	.140	.137
74A, 740	70-72	.90	8, 92	.147	.142
740, 75A	70-73	.39	8, 144	.132	.129
75A, 750	70-73	.81	8, 144	.142	.140

Note: 71A, 72A and 720 are pooled to increase degrees of freedom.

Table 7: Regression of 1/MPG on physical characteristics (1974-77 vintage cars)

Physical characteristics	Estimated coefficient	t-value
Constant	.194 E-1	4.209
CID	.125 E-3	10.478
NOC	.886 E-3	1.548
WT	.950 E-6	1.063
WBW	-.409 E-6	-.578
NOD2	-.198 E-3	-.215
NOD5	.213 E-2	1.758
AT	.473 E-2	3.455
PS	-.103 E-3	-.077
AC	-.478 E-2	-2.693
VT74	.228 E-1	21.975
VT75	.101 E-1	9.948
VT76	.195 E-2	1.995
No. of obs.	472	
R^2	.860	

Note: See section III and IV for the abbreviations of physical characteristics. VT74 is a dummy for the 1974 vintage and so on (1977 vintage as base).

Appendix

Table A1: The Sample

Vintage	No. of observations	Year·month when used car prices available
1966	64	1970A*, 71A*, 720
67	63	70A*, 71A*, 720, 730
68	62	70A*, 71A*, 720, 730, 74A, 740
69	60	70A*, 71A*, 720, 730, 74A, 740, 75A, 750
1970	126	700, 71A, 710, 72A, ---, 760
71	124	710, 72A, 720, 73A, ---, 770
72	119	720, 73A, 730, 74A, ---, 780
73	113	730, 74A, 740, 75A, ---, 790
74	111	740, 75A, 750, 76A, ---, 800
75	117	750, 76A, 760, 77A, ---, 81A
76	123	760, 77A, 770, 78A, ---, 81A
77	122	770, 78A, 780, 79A, ---, 81A
78	136	780, 79A, 790, 80A, 800, 81A
79	144	790, 80A, 800, 81A
80	143	800, 81A

Note: * denotes Central Edition used car prices and those without * are taken from New England Edition of N.A.D.A.

Table A2: E.P.A.'s MPG data

Vintage	City MPG	Highway MPG	MPG combined
1974	A	N.A.	N.A.
75	A	A	N.A.
76	A	A	A
77	A	A	A
78	A	A	A
79	N.A.	N.A.	A
80	N.A.	N.A.	A

Note: A - available, N.A. - not available

Table A3: Consumer Reports' MPG data

Vintage	No. of observations
1966	20
67	20
68	23
69	21
70	19
71	24
72	17
73	27

Footnotes

1. Kahn (1981) has also analyzed the effect of gasoline price increase on used car prices. Our work differs from his in important points. Our null hypotheses and methods are different. We focus directly on the change in imputed prices of large, medium and small cars. We use seemingly unrelated regression methods and a much larger data set. Nevertheless, this does not detract from the pioneering merit of his work.

2. There might be some patriots who made gasoline cost a direct argument of their utility function: the amount of gasoline used may by itself now result in disutility. But since scarcity of gasoline is reflected in its price in a market economy, rational consumers have only to consider the cost of gasoline in their budget constraint and do not have to make the amount of gasoline used an argument of the utility function. We assume that the number of such patriots is small. Consumers may have overreacted to gasoline price increase, holding an unrealistic expectations of additional gasoline price rises in the future. In this case, relative quality evaluation among cars may have been influenced more by the energy crises than our models allow.

3. The relation between the market price and the full price is given by equation (6) in section II.

4. Economists usually leave it to others (perhaps sociologists and psychologists) to explain how consumer preferences are formed and change. Discussions of endogeneous taste change are an exception but this is a very restricted form of change (see Phlips, 1974). As Hirshleifer notes, really great social

changes in human history may have stemmed from shifts in people's goals for living (that is, preferences), but economists have very little to say on this topic.

5. Note that we ignore other components of user costs such as repairs, taxes, and insurance.

6. Alternatively, we could have defined a semi-logarithmic hedonic function to start out with. That is, equation (6) could have been defined as

$P + g = e^{\Sigma\alpha_i x_i}$ which after several steps would have lead to the form $\log P \simeq \Sigma\alpha_i x_i - g/P$, which is essentially the same as (17).

7. We will estimate the quality-adjusted full price index in a separate paper.

8. Also, as stated before in Section II, x and MPG are consumer decision variables (that is endogenous variables). We do not take this into consideration in the actual regression as in the usual hedonic studies, since from the point of view of the used car market, the x's and MPG's are predetermined.

9. E.g., see Theil (1971, pp. 548-549).

10. Equation (4.3) of Leamer (1978, pp. 88) shows the following relation between the F-value and the number of observation n for OLS regressions.

$$F = \left(\frac{R_1^2 - R_0^2}{1-R_1^2} \right) \left(\frac{n-k}{q} \right)$$

Here R_1^2 is R^2 of the unconstrained regression, R_0^2 is R^2 of the constrained, K is the number of parameters in the unconstrained and q is the number of parameters to be constrained. R^2's do not change much in large samples and hence the F-value increases with n.

11. The information on the 1970-80 vintages was taken from the New England Edition of the N.A.D.A. Guide. Data on the 1966-69 vintages were taken from the earlier Ohta-Griliches (1976) study which used the Central Edition of the same Guide. One should be careful not to confuse Central Edition used car prices with those of the New England Edition. 1970A and 1971A used car prices of 1966-69 vintages are Central Edition prices and all other prices are New England Edition prices, as shown in Appendix Table A1. Our sample distribution is shown in that table also.

12. AC is standard equipment on high-priced cars (Cadillac, Imperial, Lincoln). As Ohta-Griliches (1976) show, the make effects (effects of omitted characteristics on price) of these cars are around .4, which is roughly equal to the estimated coefficient of AC in this study.

13. We also computed such estimates using three periods at a time, rather than two, and looked at changes a year apart, rather than just six months apart, with essentially similar results.

14. The Bayesian critical F-value is between 4.0 and 5.2 for these samples.

15. We did similar calculations for the 1973O - 1974A change with similar results.

16. Wilcox (1978) used the regression of MPG on physical characteristics in a different context.

17. Actually in the multi-period model, $g = \sum_{t=1}^{T} p_g(t)K(t)/(1+r)^t P$. As a rough calculation, let $p_g(t) = p_g(1)(1+a)^t$ where $a = r$, $p_g(1) = 1$, and $K(t) = 10000$, $P = 5000$ and $T = 5$. Then $g = 10$.

References

Arrow, K.J. (1960), "Decision Theory and the Choice of a Level of Significance for the t-Test," in Ingram Olkin et al (eds.) Contributions to Probability and Statistics, pp. 70-78, Stanford: Stanford University Press.

Becker, G.S. (1965), "A Theory of the Allocation of Time," Economic Journal, September.

Berndt, E.R. (1983), "Quality Adjustment in Empirical Demand Analysis," Working Paper No. 1397-83, A.P. Sloan School of Management, M.I.T., January.

Boyd, J.H. and R.E. Mellman (1980), "The Effect of Fuel Economy Standards on the U.S. Automotive Market: An Hedonic Demand Analysis," Transportation Research, Oct./Dec.

Carlson, R.L. (1978), "Seemingly Unrelated Regression and the Demand for Automobiles of Different Sizes, 1965-75: A Disaggregate Approach," Journal of Business, vol. 51, no. 2.

Consumer Union, Consumer Reports.

Court, A.T. (1939), "Hedonic Price Indexes with Automotive Examples," in The Dynamics of Automobile Demand, New York: General Motors Company, 99-117.

Daly, G.G. and T.H. Mayor (1983), "Reason and Rationality during Energy Crises," Journal of Political Economy, February.

Gordon, R.J. (1983), "Energy Efficiency, User-Cost Change, and the Measurement of Durable Goods Prices," in M.F. Foss, ed., The U.S. National Income and Product Accounts: Selected Topics, Studies in Income and Wealth, Vol. 47, The University of Chicago Press for the National Bureau of Economic Research.

Griliches, Z. (1961), "Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change," in NBER, The Price Statistics of the Federal Government, General Series, No. 73, New York, 137-196.

Greenlees, J. S. (1979), "Gasoline Prices and Purchases of New Automobiles," Working Paper 91, Bureau of Labor Statistics, U.S. Department of Labor, June.

Hall, R. E. (1971), "The Measurement of Quality Change from Vintage Price Data," in Price Indexes and Quality Change, Z. Griliches ed., Cambridge: Harvard University Press.

Hirshleifer, J. (1976), Price Theory and Applications, New Jersey: Prentice Hall.

Kahn, J. A. (1981), "The Adjustment of the Used Automobile Market to Gasoline Price Shocks: An Asset Approach," Honors A. B. thesis, Department of Economics, Harvard University, March.

Lancaster, K. J. (1971), Consumer Demand: A New Approach, New York: Columbia University Press.

Leamer, E. E. (1978), Specification Searches: Ad Hoc Inference with Non-experimental Data, New York: John Wiley & Sons.

Lucas, R. E. B. (1975), "Hedonic Price Function," Economic Inquiry, June.

Manski, C. F. (1980), "Short Run Equilibrium in the Automobile Market," Discussion Paper No.8018, The Maurice Falk Institute for Economic Research in Israel, November.

Muellbauer, J. (1974), "Household Production Theory, Quality and the 'Hedonic Technique'," American Economic Review, December.

National Automobile Dealers Association (N.A.D.A.), Official Used Car Guide, New England Edition for 1970-80 vintages and Central Edition for 1966-69 vintages.

Ohta, M. (1980), Hinshitsu to Kakaku: Atarashii Shōhisha no Riron to Keisoku (Quality and Price: Theory and Method of New Approach to Consumer Behavior), Tokyo: Sōbunsha, in Japan.

Ohta, M. and Z. Griliches (1976), "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis," in Household Production and Consumption, N.E. Terleckyj ed., New York: N.B.E.R..

Phlips, L. (1974), Applied Consumption Analysis, Amsterdam: North-Holland.

Theil, H. (1971), Principles of Econometrics, New York: John Wiley & Sons.

U.S. Bureau of Labor Statistics, The Consumer Price Index.

U.S. Environmental Protection Agency (E.P.A.), Gas Mileage Guide for Car Buyers, available after 1974.

Waugh, F.V. (1928), "Quality Factors Influencing Vegetable Prices," Journal of Farm Economics (10) April, 185-96.

Wilcox, J.A. (1978), "Automobile Gasoline Mileage and the Costs of Environmental Regulations," Unpublished, University of California - Berkeley.