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Gasoline Price and Passenger Car Prices in the United States for 1970-81: Did Consumers Change Relative Quality Evaluations among Cars?

by

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Contents

I. Introduction

There were energy crises (or oil shocks) in 1973 and 1979, when gasoline price increased dramatically, as seen in the consumer price index (abbreviated as CPI) of gasoline (Table 1). By these two crises, consumers changed their demands for automobiles, and automobile manufacturers tried to adjust their products and prices to changes in consumer demands. These changes can be observed from three points of view: (1) Quantity --- increase in market share of small cars relative to large cars, (2) Price --- increase in price of small cars relative to large cars, or change in imputed prices of automobile characteristics (such as weight, cubic inch displacement of engine, mileage per gallon of gasoline (abbreviated as MPG), etc.), (3) Quality (characteristics of automobiles) --- downsizing of length, weight, horsepower, etc., and increase in MPG.

The effect of gasoline price increase on automobile demand is analyzed usually from the viewpoint of quantity such as quantity demanded or market share, namely, from the primary point of view (Carlson (1978), Greenlees (1979), Boyd and Mellman (1980)).

Our research tries to analyze the effect from the dual point of view, namely, from price. In other words, we will analyze the effect of gasoline price increase on automobile prices.[1] As will be described in section II, we use hedonic hypothesis so that automobile price is a function of its characteristics. Hedonic approach allows us to estimate imputed prices of automobile characteristics by regression. So, our research tries to examine the effect of gasoline price increase on the imputed prices of automobile characteristics. Since the estimated quality of a car is the product sum of the imputed prices of characteristics and the characteristic levels of the car, our research analyzes the effect of gasoline price increase on the quality evaluation of cars.

Used car market is our source of information, whereas "quantity" people examined the effect of gasoline price increase on share in new car market. The reason is as follows for using used market in this study. In the used car market, quantity of cars are fixed and prices are determined primarily by consumers, and therefore used car prices can be assumed to reflect consumers' evaluation of cars correctly. New car prices are set by automobile manufacturers and may not reflect consumer evaluation correctly.

Superficially, we may think that consumers changed quality evaluation of cars in favor of small cars relative to large cars in face of the two energy crises, because small cars are more efficient in fuel economy (measured by mileage per gallon which we abbreviated as MPG) than large cars. Relative estimated quality between two cars is the ratio of the product sums of the imputed prices of characteristics and the characteristic levels of the two cars that are arguments in the consumer utility function.[(2)] Since the amount of gasoline used does not enter utility function but enters only budget constraint, there is a possibility that the relative estimated quality did not change in the energy crisis, if gasoline cost is properly taken into account. The main purpose of this paper is to examine this possibility empirically.

If we define the full price of an automobile as the sum of its market price and the gasoline cost for operating it, we can restate the previous paragraph as follows. The relative market price of small cars may have increased as compared with large cars by the oil shocks, but the change in the relative full price is expected to have been smaller than the change in the relative market price.[3]

As will be seen in section II, imputed prices of characteristics depend on the consumer's taste (that is, preference relation or the form of utility function) as well as on other factors. So, if there is a taste change (that is, a change in the preference relation), imputed prices of characteristics change. Therefore, if the imputed prices do not change, we expect that there is no consumer taste change.

The hypothesis of no consumer taste change is important for economic analysis, namely, for comparative static analysis of consumer behavior. This is illustrated by the following example taken from Hirshleifer (1976, pp.11). When economists try to explain the effect of the imposition on consumer demand of a tax on liquor, economists "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 explain the effect of parameter change such as the imposition of tax or gasoline price increase on consumer demand by comparative statics, if consumers change their preferences in a manner which is unknown to economists.[4]

If gasoline cost is not taken into account, we expect that there were big changes in the imputed prices of automobile characteristics and in the relative estimated qualities among cars. We want to know if these changes finished as soon as oil shocks were over. If it is the case, then we may say that the U.S. consumers were very quick in adjsuting quality evaluations of cars to gasoline price increase. This paper will examine this, too.

II. Model, Implication and Statistical Method

We follow hedonic hypothesis so that automobile price is a function of its characteristics and use hedonic approach to estimate imputed prices of characteristics by regressing price on characteristics. As Muellbauer (1974), Lucas (1975) and Ohta (1980) showed, hedonic hypothesis can be based on Lancastrian theory of consumer.

We start from considering a simple one-period model of consumer behavior to make clear the distinction between those characteristics that enter utility function and those that do not enter utility function but enter budget constraint. Suppose that there are two kinds of goods, automobiles and other goods. Let $y = (y_1, y_2, \ldots, y_m)$ be a vector of automobile performances such as speed, roominess, conditions of ride, handling, etc. Let $x = (x_1, x_2, \ldots, x_n)$ be a vector of physical characteristics of an automobile such as weight, length, horsepower, etc. Then, primarily, y (not x) enters consumer utility function. But following the two-stage hypothesis of Ohta-Griliches (1976), y can be thought of as a function of x. We assume that this function is stable over the observation period. Then, we may postulate a 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 be chooses the model of a car (that is, characteristics of a car) to buy. Then, rational consumer behavior can be formulated by the following maximization problem.

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

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

Here $P(x, MPG)$ is the price of a car with characteristics $x = (x_i)$ and mileage 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 for driving a car.

Letting λ be a Lagrange multiplier, the first order condition is as follows for the above maximization problem.

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

Here u_{x_i} denotes $\partial u/\partial x_i$, P_{x_i} denotes $\partial P(x, MPG)/\partial x_i$, etc. The number of variables is equal to the number of equations $(n + 4)$ and so the consumer decision variables x, MPG, K can be obtained as functions of p_g, p_z, m and the functional form of $P(x, MPG)$.

The following quadratic approximation will be general enough to the hedonic price function $P(x, MPG)$.

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

where

$$\phi_{ij} = \phi_{ji}. \quad (2)$$

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

$$\alpha_i' + 2\phi_{ii} x_i + \sum_{j\neq i} \phi_{ij} x_j + \mu_i(1/MPG) = p_z \cdot u_{x_i}/u_z$$

$$\beta + 2\phi \cdot (1/MPG) + \sum_i \mu_i x_i = -p_g \cdot K \qquad (3)$$

Substituting equation (3) into (2), we obtain the following.

$$P(x, MPG) = \sum_i \alpha_i x_i - p_g \cdot K/MPG - \sum_i \phi_{ii} x_i^2$$

$$- \phi(1/MPG)^2 - \sum_i \mu_i (1/MPG) x_i \qquad (4)$$

where

$$\alpha_i = p_z \cdot u_{x_i}/u_z.$$

First we test the null hypothesis of no effects of quadratic terms of $x = (x_i)$ and $1/MPG$. The constrained regression equation is the following, where P is replaced by $\log P$ on the left hand side as in the usual semilogarithmic hedonic regression equation.

$$P(x, MPG) = \sum_i \alpha_i x_i - p_g \cdot K/MPG - \sum_i \mu_i (1/MPG) x_i \qquad (5)$$

The unconstrained regression equation is (4), where we replace P by $\log P$ on the left hand side and we omit the cross terms of x's.(5) Since we do not have data of p_g and K, we replace $p_g \cdot K/MPG$ by the following in actual regressions, as we will explain later in this section.

$$p_g \cdot K/MPG \doteq \beta'/MPG + \gamma s + \varepsilon s/MPG \qquad (6)$$

where s is the age of the car. We use dummies for various vintages of cars.

The sample is U.S. domestic cars of 1974-78 vintages. The number of observations is 607. Section III shows the characteristics used in the regression. For 19790 (0 denotes October) used car prices, the F-value is .74 with 4 and 579 degrees of freedom. The difference of the standard error of regression between the constrained and the unconstrained (denoted as ΔSER) is .0003. For 19800 prices, the F-value is 4.64 and ΔSER is .0003. Since the sample is large, we use Leamer's Bayesian critical level (pp.114 of his book), as we will explain later in this section. This critical F-value is 6.25 in this case. As we will explain later, we use ΔSER as another test statistic and consider .015 as the critical level in the test using single equation. So both F-test and ΔSER test do not reject the null hypothesis of no effects of the quadratic terms and we can reduce equation (4) to (5).

Second we examine the significance of cross terms of 1/MPG and x. That is, we test if we can reduce equation (5) to (7).

$$P(x, MPG) = \sum_i \alpha_i x_i - p_g \cdot K/MPG \qquad (7)$$

In actual regressions, we replace P by logP on the left hand side, $p_g \cdot K/MPG$ by equation (6) and use dummies for various vintages of cars. We test the hypothesis for 19790 and 19800 prices, using the same sample as above.

For 19790 prices, the F-value is 10.75 with 9 and 583 degrees of freedom, and ΔSER between the constrained and the unconstrained regression is .013. For 19800 prices, the F-value is 13.92 and ΔSER is .018. The Leamer's critical level is 6.46 in this case, and our critical ΔSER is .015. So, the cross terms of 1/MPG and x are significant and we cannot reduce (5) to (7). In other words, 1/MPG is not separable from x's. This rejection is understandable, because 1/MPG is deeply related to x's as shown in Table 4.(6)

As we will explain later, we have to use SUR (seemingly unrelated regression) instead of OLS (ordinary least squares). When we use SUR, we have to reduce the number of parameters so that the operation is feasible within the limitation of the statistical computer package used (that is, TSP). Because of this limitation, we had to use equation (7) instead of (5). The specification error that we commit is taken care of to some degree by SUR.(7)

Thus we assume equation (7), which assumes the following hedonic price function instead of a more general form (2).

$$P(x, MPG) = \sum_i \alpha_i x_i + \beta \cdot (1/MPG) \tag{8}$$

Utility maximization condition (3) becomes as follows under this hedonic price function.

$$\left.\begin{aligned} \alpha_i &= p_z \cdot u_{x_i}/u_z \\ \beta &= -p_g \cdot K \end{aligned}\right\} \tag{9}$$

Imputed price of characteristic i, α_i, is the marginal utility of the characteristic in terms of numéraire z. We should note that β does not depend directly on utility funciton but depends indirectly through K. This is because gasoline cost does not enter utility function but enters budget constraint.

α and β are determined by demand for and supply of various models of used cars in market equilibrium. So they can change over time satisfying equation (9). Equation (9) indicates that α and β are related to p_g, p_z, x, z, K and the form of utility function (that is, taste).

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 consumer taste.

Therefore, if taste change occurs, then relative values of α's change. This implies that if there is no change in relative α's, then there is no taste change. The purpose of this paper is to test the null hypothesis of the constancy of the relative values of α's. We should note here that even if the null hypothesis is rejected, it does not necessarily imply consumer taste change. This is because relative values of α's depend not only on the form of utility function but also on the level of x.

Evaluation (7) shows that the market price of a car with characteristics x and MPG, $P(x, MPG)$ 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 operation cost (gasoline cost, $p_g \cdot K/MPG$, in this case).

Equation (7) can be rewritten as follows.

$$P(x, MPG) + p_g \cdot K/MPG = \sum_i \alpha_i x_i \qquad (10)$$

The left hand side is the sum of the market price of a car and the gasoline cost to operate it. Following the terminology of household production theory of Becker (1965), this sum is interpreted as the full price of the car. The above equation shows that this full price can be estimated as the product sum of characteristics of the car (excluding MPG) and imputed prices of characteristics, that is, estimated quality of the car.

It is assumed in constructing quality-adjusted consumer price index of a commodity by price link that the market price ratio of goods at a certain specific time point is equal to their quality ratio. Equation (10) shows that this assumption is wrong. According to (10), quality ratio (ratio of $\Sigma\alpha_i x_i$) is not equal to market price ratio (ratio of P(x, MPG)) but equal to full price ratio (ratio of P(x, MPG) + $p_g \cdot K/MPG$). In other words, we have to consider full price instead of market price to obtain true quality-adjusted price index of automobile.

To estimate the quality-adjusted full price index as the true quality-adjusted price index, let us write the relative imputed price of characteristic i by α_i and its absolute level by $\bar{P}$, and write gasoline cost $p_g \cdot K/MPG$ by g. Then equation (7) is written as follows.

$$P(x, MPG) = \bar{P}\Sigma \alpha_i x_i - g \qquad (11)$$

Here $\bar{P}$ can be interpreted as quality-adjusted full price index. In the actual estimation, we will parameterize g as we will explain later.[8]

Let us digress further from the formulation of the regression equation to see the implication of our null hypothesis of the constancy of relative imputed prices of characteristics $\alpha = (\alpha_i)$. Suppose gasoline price p_g changes. Let us write the values of variables after the gasoline price change by putting ~ on the variables. Then, the null hypothesis implies the following equation from (11).

$$\frac{\tilde{P}(x, MPG) - P(x, MPG)}{P(x, MPG)} = \frac{\tilde{\bar{P}}}{\bar{P}}\{\frac{\tilde{\bar{P}} - \bar{P}}{\tilde{\bar{P}}} + \frac{1}{P(x, MPG)}(g - \tilde{g}\frac{\bar{P}}{\tilde{\bar{P}}})\} \qquad (12)$$

Equation (12) decomposes price change of a specific car model due to gasoline price change into two parts under the hypothesis of the constancy of $\alpha = (\alpha_i)$: Change in the quality-adjusted full price index and change in the gasoline cost. The former change takes the same value to all the car models but the latter change takes different values to different car models. So the relative price structure among car models changes when gasoline price changes. Suppose that the ratio of the price of a large car with respect to that of a small car declines due to gasoline price increase. Then equation (12) implies that the ratio of the change in gasoline cost with respect to the car price is larger in absolute value for large cars than for small cars.

Thus, even if there is no consumer taste change (that is, no change in $\alpha = (\alpha_i)$), the relative price structure can change when gasoline price changes. In other words, we should note here that the change in the relative market price structure among full-sized, intermediate and compact cars does not necessarily imply consumer taste change.

When oil price increases, it will generally be the case that $\tilde{g} > g$ and $\tilde{\bar{P}} > \bar{P}$, where the latter relation is expected because of the inter-industry input-output relationship and the increase of energy cost. Then the first term in the right-hand side of equation (12) is positive and the second term is negative. So it is possible that the energy crisis increases the prices of some cars (typically compact cars) in absolute values, while decreasing the prices of other cars (typically full-sized cars).

If there is no change in price index so that $\bar{P} = \tilde{\bar{P}}$, then equation (12) reduces to the following.

$$\frac{\tilde{P}(x, MPG) - P(x, MPG)}{P(x, MPG)} = -\frac{\tilde{g} - g}{P(x, MPG)} \qquad (13)$$

So, when $\tilde{g}$ is larger than g because of gasoline price increase, the prices of all the car models (including compact cars) decline.

Further if mileage driven (K) is unchanged irrespective of gasoline price increase, then (13) becomes as follows.

$$\frac{\tilde{P}(x, MPG) - P(x, MPG)}{P(x, MPG)} = - \frac{g}{P(x, MPG)} \cdot \frac{\tilde{p}_g - p_g}{p_g} \qquad (14)$$

In this case, the prices of all the car models decline proportionately to the rate of increase of gasoline price. The constant of proportionality $(g/P(x, MPG))$ is, however, different for different car models. Since gasoline prices are common to all the car models, the above equation implies that those cars with high gasoline cost-price ratio $(g/P(x, MPG))$ show larger rate of price decline than those with small gasoline cost-price ratio.

Now we return to the formulation of the regression model. Since automobile is a durable good, we have to consider multi-period problem. Let $P_{tv}(x, MPG)$ be the price of a car of vintage v at time t with characteristics x and MPG when new. Then the age of this car, s, is $s = t - v$ at time t. Characteristics x and MPG deteriorate with age s and so we write $x(s)$ and $MPG(s)$ to express this clearly, and write x and MPG as the characteristics when new. 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 and so we write $\alpha_i(t)$ and $K(t)$ to denote this dependence. We denote the length of life of a car by T. As Manski (1980) showed, T is a consumer decision variable (scrappage rate in his case) and will depend on time t.

Following Hall (1971) and Kahn (1980), we formulate the automobile price as the discounted sum of its rental price over life time. We can interpret P in the one-period model as rental price of a car. Letting r as interest rate, we obtain the following price equation from (7).

$$P_{tv}(x, MPG) = \sum_{k=0}^{T(t)-t+v} \frac{1}{(1+r)^k} \left(\sum_i \alpha_i(k+t)x_i(k+t-v) - \frac{p_g(k+t)\cdot K(k+t)}{MPG(k+t-v)}\right) \quad (15)$$

$\alpha_i(k + t)$ is the imputed price of characteristic i at time $k+1$ expected by the consumer at time t. The consumer calculates this expected value by using his optimization rule (1) and his expected values of all the prices of goods and his expected income. We assume that the future relative imputed prices of characteristics are expected to be constant over time and that they are equal to those at present, namely, at time t. Then, 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.

$$\alpha_i(k + t) = \overline{P}_t\ \alpha_i(t)\ \Gamma_1(k) \quad (16)$$

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

$$\left.\begin{aligned} p_g(k + t) &= p_g(t)\cdot\Gamma_2(k) \\ K(k + t) &= K(t)\cdot\Gamma_3(t) \end{aligned}\right\} \quad (17)$$

$\Gamma_2(t)$ represents the rate of gasoline price inflation at time $k + t$ expected by the consumer at time t. $\Gamma_3(t)$ is the rate of increase of mileage driven at time $k + t$ expected at time t.

We assume such a deterioration of characteristics that we can write $x_i(k + t - v) = x_i \cdot \phi(k + t - v)$ for all i. This assumes equal rate of deterioration across all the characteristics, which is equal for all the car models. We write $MPG(k + t - v) = MPG/\psi(k + t - v)$. This assumption of deterioration, the assumptions of expectation (16) and (17) allow us to write (15) as follows.

$$P_{tv}(x, MPG) = \overline{P}_t \cdot \Phi(s) \cdot \sum_i \alpha_i(t) \cdot x_i - \Psi(s) \cdot p_g(t) \cdot K(t)/MPG \tag{18}$$

where $s = t - v$ (that is, age of the car) and $\Phi(s)$ and $\Psi(s)$ are defined as follows.

$$\Phi(s) = \sum_{k=0}^{T-t+v} \phi(+ t - v) \cdot \Gamma_1(k)/(1 + r)^k$$

$$\Psi(s) = \sum_{k=0}^{T-t+v} \psi(k + t - v) \cdot \Gamma_2(k) \cdot \Gamma_3(k)/(1 + r)^k \tag{19}$$

$\Phi(s)$ is the index of depreciation of all the characteristics except MPG of a car of age s and $\Psi(s)$ is the index of depreciation of MPG of a car of age s. These depreciation indexes are influenced by $\Gamma_1(k)$, $\Gamma_2(k)$ and $\Gamma_3(k)$. But these expectation terms are common to all the car models.

Equations (18) and (19) show that the change of automobile price over time depends on many things: Changes in quality-adjusted price index $\overline{P}_t$, the economic life time of a car T which affects depreciation terms $\Phi(s)$ and $\Psi(s)$, the relative imputed prices α, characteristics x and MPG when new, mileage driven K, gasoline price, expectations about future prices, especially, gasoline price, and expectation about future mileage driven. Note that change in imputed prices of characteristics is one of the important factors that affect automobile price structure.

Putting $g(1/MPG, s{:}t) = \Psi(s)p_g(t)K(t)/MPG$, we have the following equation from (18).

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

Taking logarithm, we have the following.

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

Approximating the fourth term of the right hand side of the above equation using Taylor expansion, we have the following.

$$\log P_{tv} \doteq \log \overline{P}_t + \log \Phi(s) + \log(\sum_i \alpha_i(t)\cdot x_i) - g(1/MPG,\ s:t)/P_{tv} \quad (20)$$

We approximate $g(\cdot)$ as follows.

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

Here, we should note that the parameters β, γ and ε depend on gasoline price among others. Further we use semilogarithmic form of hedonic price function, and so we write $\sum_i \alpha_i(t)\ x_i$ instead of $\log(\sum_i \alpha_i(t)\ x_i)$. We use dummies to estimate the hedonic price index $\overline{P}_t$ and depreciation term $\Phi(s)$. In the above setting, equation (2) can be written as follows.

$$\log P_{tv}\ (x,\ MPG) = \sum_k \pi_k\ T_k + \sum_s \delta_s\ D_s + \sum_i \alpha_i(t)\ x_i - (\beta(t)/MPG + \gamma(t)\cdot s + \varepsilon(t)\cdot s/MPG)/P_{tv} \quad (21)$$

Here T_k is a time dummy for time k and D_s is an age dummy for age $s = t - v$.

The purpose of this paper stated before is, then, to test the constancy of $\alpha(t) = (\alpha_i(t))$ over time in equation (21). Note that β, γ and ε are allowed to change over time in the test, because these parameters do not reflect marginal utilities of characteristics but reflect gasoline price, automobile prices, general price level and income. Age coefficient δ_s is allowed to change also over time in the test, because deterioration pattern may be different for different vintages. When using (21) as a regression equation, we first regress P on characteristics x to get its estimate $\hat{P}$ and then do a second regression replacing P on the right hand side of (21) by $\hat{P}$.(9)

If gasoline cost is not taken into consideration as in the usual hedonic study, then (21) reduces to the following.

$$\log P_{tv}(x, MPG) = \sum_k \pi_k T_k + \sum_s \delta_s D_s + \sum_i \alpha_i(t) x_i \qquad (22)$$

We also test the null hypothesis of the constancy of α over time in (22). This hypothesis will be rejected strongly in the energy crises. We want to know if U.S. consumers were quick in adjusting α to gasoline price increase.

In equation (21), parameters β, γ and δ depend not only on gasoline price but also on other things such as automobile prices, general price level and income. We are also interested in taking only the effect of gasoline price increase into account, holding other things constant.

We will explain below how to do this analysis, returning (21) back to the following equation, where we drop time and age dummies for simplicity of exposition.

$$\log P(x, MPG) = \sum_i \alpha_i x_i - g\cdot(1/MPG) \qquad (23)$$

where $g = p_g\cdot K/P(x, MPG)$.

We also consider the followings.

$$1/MPG = \sum_i \mu_i x_i \qquad (24)$$

$$\log P(x, MPG) = \sum_i \rho_i x_i \tag{25}$$

The argument of omitted variables gives us the following relation.[10]

$$\rho_i = \alpha_i - g \mu_i \tag{26}$$

Suppose gasoline price increases by 100σ%, holding other things constant. Then g increases also by 100σ%. Letting $\tilde{\rho}_i$ be the value of ρ_i after this increase, we have the following equation from (26).

$$\tilde{\rho}_i = \alpha_i - (1 + \sigma)g \mu_i = \rho_i - \sigma g \mu_i \tag{27}$$

Now we can examine the effect of gasoline price increase isolated from other changes in the following way. The constrained equation is (25) where ρ is replaced by $\tilde{\rho}$ of (27). The unconstrained equation is (25) where ρ's are free parameters to be estimated. In both regressions, P(x, MPG) is the price after the gasoline price increase. If SER of the constrained regression is not much larger than that of the unconstrained, then the change in the imputed prices of automobile characteristics is explained mostly by the gasoline price increase: Other factors such as general price level and income do not affect the imputed prices much.

In the actual regressions of (21) and (22), we use SUR (seemingly unrelated regression). The reason is as follows. There must be omitted characteristics in (21) and (22) and the cross terms of 1/MPG and characteristics x are omitted as stated before, and so the correlation between the residuals for the years compared are high for each car model. Actually, the correlation coefficient is something like 0.9. Another way to reduce the effect of omitted characteristics is to use dummies for car makes. But even if we use these make dummies, the correlation coefficient is still high (around 0.7). So we have to use SUR. Because of the limitation of the memory of the computer program TSP, we do not use make dummies for almost all the regressions.

The testing F-statistic in SUR is given in Theil (1971, equation (3.6) in pp.314), where the correlations of residuals among equations are taken into account. The F-test has a following shortcoming, as Leamer (1978) points out. As the number of observations becomes large, the F-value tends to become large and the critical F-level becomes small.[11] So the null hypothesis is rejected almost always for very large sample (Our sample size is something like 500). Therefore the significance level should be a decreasing function of sample size.

For this, Leamer gives a following Bayesian critical level L_B under the assumption of diffuseness. We will use this critical level in the F-test.

$$L_B = (n - k)\cdot(n^{q/n} - 1)/q \qquad (28)$$

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 testing the null hypothesis, we not only look at F-value in the SUR framework, but also look at the standard error of regression (abbreviated as SER). Following 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 .015 in any equation of the system under the test, we do not reject the null hypothesis practically. If it is greater than .015 in some equation, we reject the null hypothesis practically. Since the left hand variable is the logarithm of price in our regression, increase in SER by .015 implies the decrease of the explanation of price by 1.5%. Since SER of our regression is around .2 , .015 is about 7.5% of it. We call this test ΔSER test.

ΔSER test examines if there is a difference in the relative estimated quality among cars by the imposition of the null hypothesis of the constancy of relative imputed prices of characteristics over time. The reason is as follows. Let $x_k = (x_{ik})$ be the vector of characteristics of car model k. Let $\alpha_t = (\alpha_{it})$ be 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 relative estimated quality between models a and b at time t, where $\hat{\alpha}_t$ denotes the estimate of α_t. Since the left hand variable is the logarithm of price, ΔSER measures the degree of the difference in the fitted values (that is, relative estimated quality) caused by the null hypothesis, if we deduct appropriately the general price level of time t from α_t.

Since consumers buy a bundle of characteristics x embodied in a car, the change in the relative quality $\alpha \cdot x$ may be more interesting to them than the change in the ratios of imputed prices of characteristics α (that is, α_{it}/α_{jt} for all i, j).

If the ratios of the imputed prices are constant over time, then the relative qualities do not change. Even if there is a change in the ratios of the imputed prices, relative qualities may not change. This is because there are high multicollinearities among characteristics. For example, let $x_a = (1, 2)$ and $x_b = (2,4)$ be the vector of characteristics of models a and b. Then, the relative quality of model b to a is

2 irrespectively of imputed prices of characteristics. So, the significant changes in relative imputed prices of characteristics do not necessarily imply significant changes in relative qualities among cars.

We cannot obtain SER adjusted by degrees of freedom (that is, $SER = \sqrt{SSR/(n - NP)}$ where n, SSR and NP are the number of observations, sum of squared residuals and the number of parameters to be estimated, respectively) for each equation of the equation system under our constrained SUR, because parameters are kept to be the same among equations of the system and so we cannot calculate NP for each equation. So we tabulate SER for the equation system as a whole.

In the equation system under the test, ΔSER may be large enough to reject the null hypothesis practically for some equation, while it is small for other equations, and so it is not large for the equation system as a whole. In this case, we reject the null hypothesis practically. So we amend the ΔSER test as follows. When the number of equations is two, then we reject the null hypothesis if ΔSER of the equation system is larger than .007 (from .015/2). When the number of equations is three, the criterion is .005 (from .015/3).

III. Data

We obtain data from N.A.D.A. New England Edition on U.S. domestic passenger car prices and characteristics.(12) We collect the characteristics of 1970 to 1980 vintage cars and their used prices bi-annually (October and April) from 1970O to 1981A. The oldest car is of age 6 in the data. We do not use October used prices of new vintages for the study of used market, because transactions of these cars are not large enough to make their used prices reliable in reflecting consumer evaluations.

Numbers of observations of used car prices are small for the early seventies in the above data set. To increase the observations for these years, we use 1966-69 vintages of Ohta-Griliches (1976) data set. Used car prices of this data set were taken from N.A.D.A. Central Edition. So we should be careful not to confuse Central Edition used car prices with those of 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 Table 2.

Thus our observation period of used car prices is from 1970A to 1981A. 1966-80 vintage cars constitute our sample cars. Our sample distribution is shown in Table 2.

Ohta-Griliches' data set contains only sedans and hardtops with four or two doors, but the new data set for 1970-80 vintages contains all body types including station wagons and coupes with four, two, three and five doors. So, the former set focuses on the most popular segment of passenger car market, whereas the latter encompasses all the segments of passenger car market.

Following physical characteristics are available among others. (1) Number of cylinders, (2) shipping weight (pound), (3) number of doors, (4) wheelbase (inch), (5) length (inch), (6) width (inch), (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 air conditioning, 1 if standard, 0 otherwise). Further we have information on the makes and the introduction dates of cars.

MPG data are taken from E.P.A., but E.P.A. data are available only after 1974 vintages. Further, they are for city driving in some year and for highway or combined of city and highway driving in other years. Table 3a shows this situation. We can match our sample cars perfectly with the cars in E.P.A. publication after 1975. But for 1974, we cannot match them perfectly. When we cannot find the same car from E.P.A. as that in our sample in 1974 , we use the MPG data of the nearest car available in E.P.A. (nearest in CID and weight within the same make).

We use Facts and Figures of Consumer Reports for MPG data of 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 in stack. The size of Consumer Reports' MPG data is small as shown in Table 3b.

IV. Empirical Results

Our main concern is to see if there were significant changes in imputed prices of automobile characteristics over time in face of energy crises.

First we examine this without considering gasoline cost. Typically, we compare the imputed prices at two successive time points (at time t and $t+1$), by using the following regression equation system.

$$\log P_{tvj} = \sum_k \pi_k T_k + \sum_k \delta_{kt} V_k \;(+ \sum_k \mu_{kt} M_k) + \sum_i \alpha_{it} x_{ivj}$$

$$+ \text{disturbance}$$

$$\log P_{t+1vj} = \sum_k \pi_k T_k + \sum_k \delta_{k(t+1)} V_k (+ \sum_k \mu_{k(t+1)} M_k) + \sum_i \alpha_{i(t+1)} x_{ivj}$$

$$+ \text{disturbance} \qquad (29)$$

where P_{tvj} denotes the price of a used car of model j and vintage v at time t. T_k, V_k and M_k are dummies for time k, vintage k and make k, respectively. Make dummies are not used in almost all the regressions except in early seventies, because of memory limitation of the computer program. x_{ivj} is the level of physical characteristic i of model j and vintage v.

Our null hypothesis without the consideration of gasoline cost is that $\alpha_{it} = \alpha_{i(t+1)}$ for all i in equation (29).

Same car models enter both equations of (29). As was discussed in section II, disturbances of the two equations correlate because of omitted characteristics. The correlation coefficient is roughly .9 without make dummies in the right hand side and .7 with them. So we have to use SUR for regression. SUR estimates are the same as OLS estimates in the unconstrained regression, because both equations are linear in parameters and contain the same right hand variables. Using the unconstrained estimates, we calculate the testing F-statistic in the SUR framework, which takes correlations of disturbances between the two equations into account.

In the constrained regression where α_{it} and $\alpha_{i(t+1)}$ are constrained to be the same, SUR is more efficient than OLS and so we have to use SUR.

Following physical characteristics are, typically, used in the regressions below: (1) CID, (2) no. of cylinders (abbreviated as NOC), (3) weight (WT, in pounds), (4) wheelbase x width (WBW, in inch^2), (5) dummy for no. of doors less than 4 (NOD2), (6) dummy for no. 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, thus contributing to the condition of ride as well as (5), (6) and (9). (7) and (8) contribute to steering.

As for roominess or size characteristic, we tried length or length times width as well as WBW in preliminary studies. Their estimated coefficients are less significant and have the same sign (negative). So we use WBW rather than them.

We tried WBW and WT/WBW instead of WBW and WT for 19780-790 in preliminary studies. WT/WBW is a proxy for sturdiness of the car. WT/WBW has an insignificantly positive estimated coefficient, while WT has an insignificantly negative coefficient.(13) The estimated coefficients of explanatory variables do not change much whether we use WT or WT/WBW. So we use WT instead of WT/WBW.

The estimated coefficient of horsepower (H) tends to become smaller and less significant over time relatively to that of CID, as shown in Table 5. So we use H as well as CID in early seventies. Ohta-Griliches' data contain only six- and eight-cylinder cars and so we use a dummy for eight-cylinder car instead of using NOC in early seventies. Newly collected data contain four- as well as six- and eight-cylinder cars and so we use NOC instead of dummies to save the number of parameters to be estimated. Since is is not clear to us how NOC affects consumers' utility and MPG, we tried regressions without using NOC for 19780-790. The estimated coefficients of other characteristics are not much different whether we use NOC or not. So we use it.

We use dummies for two-door (or three-door in rare cases) and five-door cars (NOD2, NOD5) instead of using NOD, because NOD2 has a negative coefficient in early seventies and came to have a positive coefficient later.

As seen in Table 8, the estimated coefficient of AC is roughly .3 and significant. Since the left hand variable is logarithm of price, this means that the car that has AC as standard equipment is more expensive by 30 percent than the one without it. This is unrealistic. This will be because AC captures some effect of omitted characteristics.(14) We tried regressions without using AC for 19780-790, but the estimated coefficients of other characteristics are not very much different from those using AC. So we use AC.

The estimated coefficient of WBW is significantly negative. This will be mainly because of high multicollinearity among WBW and other characteristics such as CID, and partly because WBW lowers MPG, while it contibutes to roominess. Since we are interested in the significant change of the coefficients of characteristics as a whole, the wrongly-signed coefficient does not make our analysis meaningless.

We use make dummies (thirteen domestic makes of cars) to capture the effect of omitted characteristics in early seventies, but we cannot do so after early seventies because of the memory limitation of our computer package. As shown in Table 6, testing F-statistic and the difference in SER between the constrained and the unconstrained regression do not change much whether we include make dummies or not, although SER (or SSR) becomes much smaller if we include them.(15) The coefficients of make dummies are kept to be the same among the equations compared in the constrained regression. Make dummies do not lower the correlation in residuals much among the equations compared (from .9 to .7, as mentioned before). Thus the effect of omitted characteristics seems to be individual model by model effect more than make by make effect.

The testing F-statistic and SER of the constrained and the unconstrained regressions are shown in Table 6. The multiple correlation coefficient squared, R^2, is roughly .75 to .8 in these regressions, which is smaller than that of Ohta-Griliches (1976. about .97). This is because Ohta-Griliches includes make dummies and focuses only on the most popular segment of the market, whereas our study does not include make dummies and contain all the body types of passenger cars.

In Table 6, the critical F-value is about 2 to 2.5 at the 1% level of significance and so the null hypothesis of equality of imputed prices of physical characteristics over time is rejected statistically in all the periods. A Bayesian critical level given by equation (28) is 6.23 for $n = 500$, $k = 26$ and $q = 9$. It is 6.94 for $n = 1000$, $k = 26$, $q = 9$ and 6.20 for $n = 330$, $k = 39$ and $q = 18$. So the null hypothesis is rejected also by this Bayesian critical level in many periods.

But really large F-values occur in 1973O-74A, 1976O-78A (look at 1976O-77O, 1977O-78A subperiods) and 1979A-80A (that is, 1979A-79O, 19790-80A). The null hypothesis is rejected also from practical ΔSER criterion in these periods. The largest change in imputed prices of automobile characteristics occurred in 1979A-790.

Except in the above three periods, F-values are not very large and the null hypothesis is not rejected by the ΔSER criterion.

So we may say schematically that consumers changed the imputed prices of automobile characteristics significantly in 19730-74A, 19760-78A and 1979A-80A and that they did not change them very much in 1970A-730, 1974A-760, 1978A-79A and 1980A-81A.

Let us look at the first period of significant change in imputed prices, namely, 19730-74A. As shown in Table 1, gasoline price had been stable before 1973A, showed an increase of about 8% from 1973A to 19730, a very big increase of about 40% from 19730 to 1974A (first oil shock) and then became stable again after 1974A. Consumers changed imputed prices significantly in 19730-74A, but they did not change them much after 1974A. This means that consumers finished adjusting imputed prices before 1974A and they did not change relative evaluations among cars much after 1974A. So, consumers responded significantly and almost instantaneously to the first oil shock.

Table 7 shows imputed prices of automobile characteristics during this period. Consumers came to evaluate body size (WBW) and weight (WT) less and less compared with engine size (CID). Number of cyclinders (NOC) and dummy for automatic transmission (AT) came to be evaluated less over time.

Let us look at the second period of significant changes, namely, 1976-78A. In this period, only 19770-78A subperiod shows practically significant changes judged by ΔSER criterion. Other half-year subperiods (that is, 1976O-77A and 1977A-77O) do not show practically significant changes, although a year-long subperiod 1976O-77O shows practically significant changes. This will be because both the half-year subperiods show similar but small changes in imputed prices, but these small and similar changes accumulated to significant changes in the year-long period as a whole.

These similar changes in 1976O-78A are observed in Table 8. WBW and AT came to be evaluated less and less, while CID and WT were relatively stable. So the changes are similar as in 1973O-74A.(16)

Let us look at the third period of significant changes in imputed prices of characteristics, that is, 1979A-80A. This is the period of the second oil shock in 1979. Gasoline price increased rapidly in the wider period 1978O-81A, but consumers did not change imputed prices of characteristics significantly in 1978O-79A and 1980A-81A by ΔSER criterion. So, consumers adjusted their evaluations of cars very quickly, again, to drastic gasoline price increase in the second oil shock.

Table 9 shows that consumers came to evaluate WBW less and less relative to CID in 1979A-80A. Imputed prices of NOC, AT and PS became less also. These changes are similar as those in 1973O-74A and 1976O-78A.

Summing up the analyses without considering gasoline cost, consumers did not change evaluations of passenger cars very much throughout the observation period 1970A-81A, except 1973O-74A, 1976O-78A and 1979A-80A. Two of these periods (1973O-74A and 1979A-80A) are the periods of oil shocks. In these three periods of significant changes in imputed prices, consumers came to evaluate WBW less and less compared with CID and came to put less weight on NOC, AT and PS. Thus, they came to evaluate small cars with engine size relatively large to body size more over time. Consumers finished adjusting imputed prices of automobile characteristics to drastic increase in gasoline price, when oil shocks were over. So, their adjustments were very quick.

Now we proceed to test constancy of imputed prices of automobile characteristics over time with consideration of gasoline cost. The regression equation system is based on (21) and is as follows.

$$\log P_{tvj} = \sum_k \pi_k T_k + \sum_k \delta_{kt} V_k + \sum_i \alpha_{it} x_{ivj} - \frac{1}{P_{tvj}} (\beta_t \frac{1}{MPG_{vj}} + \gamma_t (t - v) + \varepsilon_t \frac{t - v}{MPG_{vj}}) + \text{disturbance}$$

$$\log P_{(t+1)vj} = \sum_k \pi_k T_k + \sum_k \delta_{k(t+1)} V_k + \sum_i \alpha_{i(t+1)} x_{ivj} - \frac{1}{P_{(t+1)vj}} (\beta_{t+1} \frac{1}{MPG_{vj}} + \gamma_{t+1}(t+1-v) + \varepsilon_{t+1} \frac{t+1-v}{MPG_{vj}}) + \text{disturbance}. \quad (30)$$

In the estimation, we first regress price P on characteristics x to obtain its estimate $\hat{P}$ and then do the SUR for the system replacing P on the right hand side by $\hat{P}$.

As stated in section II, the null hypothesis is that $\alpha_{it} = \alpha_{i(t+1)}$ for all i. Table 10 lists the testing result for 1975-81. Comparison of Tables 6 and 10 shows that testing F-values and ΔSER become small drastically when we take gasoline cost into consideration. No periods except 1979A-790 show practically significant changes in imputed prices of characteristics by ΔSER criterion if gasoline cost is taken into consid-ration, while 19760-78A and 1979A-80A did if gasoline cost was not considered.

1979A-790 is on the borderline of significance by ΔSER criterion. A Bayesian significance level of Leamer given by (28) is 6.15 for $n = 500$, $k = 32$ and $q = 9$. It is 6.90 for $n = 1000$, $k = 32$, $q = 9$ and 5.71 for $n = 330$, $k = 32$, $q = 9$. So no periods except 1979A-790 show the significant changes by the Bayesian test.

1979A-790 shows just significant changes in the imputed prices even if gasoline cost is taken into consideration, although the significance is reduced much by the consideration of gasoline cost. Table 11 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 9. So, from the ex-post point of view, consumers over-reacted to the second oil shock in 1979.

Table 13 lists the results of testing the constancy of the imputed prices of characteristics over time with the consideration of gasoline cost for 1970-75, using Consumer Reports' MPG data. Table 12 lists the results without taking gasoline cost into consideration, using Consumer Reports' sample cars. Comparing Table 12 with Table 6, we notice that the testing F-value is much smaller in Table 12. This is partly because Consumer Reports does not include high priced cars so that its sample represents more homogeneous part of the market, but partly because the size of the data is much smaller in Table 12. But even with this small sample, the constancy of the imputed prices is rejected by the Bayesian critical level of Leamer for 19720-740 and is rejected by ΔSER criterion for 19730-74A.(17)

In Table 13, the null hypothesis of the constancy of the imputed prices is not rejected for 1970-75 both by the Bayesian critical F-value given by (28) and by ΔSER criterion.

Summing up the analyses with taking gasoline cost into consideration, the null hypothesis of the constancy of the imputed prices of characteristics is not rejected for the entire observation period 1970A-81A except 1979A-79O, both by the Bayesian F-test of Leamer and by the ΔSER criterion. Consumers changed relative evaluations among cars just significantly during 1979A-79O. They came to evaluate small cars more relative to large cars during 1979A-79O.

So far we tested the constancy of the imputed prices, using (30). In (30), parameters β, γ and ε depend not only on gasoline price but also on other factors such as automobile prices, general price level and income. Now we examine below only the effect of gasoline price increase, holding other factors constant. We will do this for 1979A-79O, following the method represented by (27). The sample consists of 1974-77 vintage cars.

First we regress log of 1979A prices on constant, vintage dummies and characteristics to obtain the estimated coefficients of characteristics $\hat{\rho}_i$. We calculate the following for 1970O prices of model j, $P_{1979O}(x_j)$.

$$LPP = \log (P_{1979O} (x_j)) - \sum_i \hat{\rho}_i x_{ij}$$

We regress LPP on constant and vintage dummies. Its SER is .228. This implies that 28.8% of 1979O prices is not explained on the average if the coefficients of characteristics are constrained to be the same as their estimates in 1979A.

Then we calculate $\tilde{\rho}_i$ of (27) by using $\hat{\rho}_i$ as ρ_i and $\sigma = .296517$ which is caluculated from CPI of gasoline price in 1979A and 1979O. We assumed $g(= p_g \cdot K/P)$ to be 1 in this calculation. We calculate LLP as follows.

$$LLP = \log (P_{1979O} (x_j)) - \sum_i \tilde{\rho}_i x_{ij}$$

We regress LLP on constant and vintage dummies. Its SER is .198. This means that 19.8% of 1979O prices is not explained on the average if the change in the coefficients of characteristics is allowed to take only the effect of gasoline price increase into account.

Finally we regress log of 1979O prices on constant, vintage dummies and characteristics. Its SER is .182. This implies that 18.2% of 1979O prices is not explained on the average even if the coefficients of characteristics are allowed to change freely from 1979A to 1979O, reflecting not only gasoline price increase but also the changes of other factors such as income and prices of the other goods.

So, SER is .228, .198 and .182, respectively, in the first, the second and the final regression above. So 65.2% of the increase of the degree of the explanation of 1979O prices by changing the coefficients of characteristics from those estimated in 1979A to those estimated in 1979O is explained by the increase of gasoline price alone, holding other factors constant.(18)

As a final analysis, we calculated relative estimated qualities among various sizes of cars over time. Five sizes of cars are considered: Full-size (Chevrolet Impala), mid-size (Chevrolet Chevelle Malibu), compact (Ford Granada), subcompact A (Ford Mustang) and subcompact B (Datsun B210). We choose a specific car model to represent each size class, which is shown in the parentheses above. These specific models are of 1975 vintage and their characteristics are shown in Table 14A.

Relative quality of car model k with respect to j is calculated by the following equation.

$$\frac{EXP(\sum_i \hat{\alpha}_i x_{ik})}{EXP(\sum_i \hat{\alpha}_i x_{ij})} - 1 = EXP\{\sum_i \hat{\alpha}_i (x_{ik} - x_{ij})\} - 1 \doteq \sum_i \hat{\alpha}_i (x_{ik} - x_{ij}) \tag{31}$$

Here x_{ij} is the level of characteristic i of model j and $\hat{\alpha}_i$ is the estimated coefficient of characteristic i in the semilogarithmic hedonic regression. (31) shows that the estimated quality of model k is higher than that of model j by $100\Sigma\hat{\alpha}_i (x_{ik} - x_{ij})\%$. When $\hat{\alpha}_i$ is obtained without consideration of gasoline cost, the relative estimated quality is the same as the relative estimated market price of the cars. When $\hat{\alpha}_i$ is obtained with consideration of gasoline cost, it is the same as the relative estimated full price.

Table 14 lists the relative estimated qualities among the five specific car models mentioned above. It lists the results without consideration of of gasoline cost and those with consideration of it. We calculate the relative qualities only for 19780-81A. This is because we want to base our estimates on large sample and this period includes the second oil shock. The characteristics used in the estimation are CID, NOC, WT, WBW and NOD.

We make the following observations from Table 14.

(a) The relative estimated quality of a larger car with resepct to a smaller car is higher when gasoline cost is taken into consideration.

(b) The relative estimated qualities are more stable over time when gasoline cost is taken into account. That is, the relative estimated quality of a larger car decreased less when gasoline cost is taken into consideration. This is especially evident in the transition of 1979A to 1979O.

(c) The relative estimated qualities changed much from 1979A to 1979O, even if we take gasoline price increase into account. But they did not change much except 1979A-79O.

(d) The change in the relative estimated quality is larger between the cars of more different sizes or characteristics (Compare full-size/subcompact B column with others).

These observations are consistent with our theory and our previous empirical test.

V. Conclusion

The purpose of this paper was to examine if the U.S. consumers changed significantly relative quality evaluations among cars in face of oil shocks in 1973 and 1979. This was done by testing the null hypothesis of the constancy of the imputed prices of characteristics over time. First we derived a hedonic model that takes gasoline cost into account, pointed out a few theoretical implications and discussed statistical methods for the estimation of the model and for the test of the null hypothesis stated above. Then we applied the model and the method to the U.S. passenger cars of used market for 1970A-81A.

Our main findings are as follows.

(a) Consumers showed significant changes in the relative quality evaluations in 1973O-74A, 1976O-78A and 1979A-80A, if we do not take gasoline cost into account. They were very quick in adjusting the quality evaluations of cars to the oil shocks.

(b) If we take gasoline cost into account, the relative estimated qualities among cars become much more stable over time. Now only the 1979A-790 period shows just significant changes in the relative estimated qualities and the significance itself decreased much even for this period.

(c) Above results were obtained by testing the null hypothesis of the constancy of the imputed prices of characteristics over time. These are supported by the comparison of the relative estimated qualities among various size classes of cars for 19780-81A, which were calculated from the estimated coefficients of characteristics.

(d) Our main model adjusts not only the effect of gasoline price increase but also the effects of the changes of other factors such as other goods' prices and income in the test of the null hypothesis stated above. We developed also a model that adjusts only the effect of gasoline price increase. We applied this model to the 1979A-790 period and observed the following. 65.2% of the increase of the degree of the explanation of 19790 prices by changing the coefficients of characteristics from those estimated in 1979A to those estimated in 19790 is explained by the increase of gasoline price alone, holding other factors constant.

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Footnotes

(1) Kahn (1981) precedes our research in that he analyzed the effect of gasoline price increase on prices, too. But our research is different from his in important points. First, our null hypotheses are not considered in his work. Second, method is different. We focus directly on the change in imputed prices of automobile characteristics, whereas he compares the relative prices of large, medium and small cars. We use seemingly unrelated regression, but he uses ordinary least squares. Third, our data set is much larger than his. Nevertheless, these differences do not hurt the pioneering merit of Kahn at all.

(2) There might be those patriots who love social justice so much that they made gasoline cost an argument of their utility functions: Amount of gasoline used themselves may now give disutility to them. But since scarcity of gasoline is reflected in its price in market economy, rational consumers have only to consider gasoline cost in budget constraint and they do not have to make the amount of gasoline used an argument of utility function. We suppose the ratio of the patriots to be small. Consumers may have overreacted to gasoline price increase, holding an unrealistically high expectation of gasoline price in the future. In this case, relative quality evaluation among cars may have been influenced much by the energy crises.

(3) The relation between the market price and the full price is given by equation (10) in section II.

(4) Consumer preferences are given to economists and it is not their main task (but perhaps the task of other scientists such as sociologists

and psychologists) to explain how consumer preferences are formed and change. So it is generally unknown to economists how consumer preferences change. An exception is a discussion on endogeneous taste change, but this is a very restricted form of change. See Phlips (1974) for endogeneous taste change. As Hirshleifer notes, really great social changes in human history may have stemmed from shifts in people's goals for living (that is, preferences). If so, economists are not good in explaining really great social changes.

(5) To reduce the number of parameters, we omitted the cross terms of x's.

(6) Those characteristics that are significant in explaining MPG have significant cross effects with 1/MPG in explaining car prices. Those that are not significant in the explanation of MPG have the insignificant cross effects. The former characteristics are CID, WBW and AC. The latter are WT, AT, NOD5 and PS (see section III and IV for these abbreviations as CID, WBW, etc.).

(7) The cross terms of 1/MPG and x's are omitted in equation (7). These omitted terms are included in the disturbance and cause correlations of disturbances in the regression equation system, as we will see later. SUR takes care of these correlations.

(8) We will estimate the quality-adjusted full price index in a separate paper.

(9) As stated before in the consumer optimization, 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 study, which will cause simultaneity biases in the estimates of parameters in (21).

(10) See Theil (1971, pp.548-549) for the argument of omitted variables.

(11) 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.

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

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 the large sample and so F-value increases as n increases.

(12) Data collection was done under Prof. E. Berndt at M.I.T. Ohta participated in that collection.

(13) WT has a positive coefficient in most years as seen in Tables 7 and 8.

(14) Those cars that have AC as standard equipment are high-priced cars (Cadillac, Imperial, Lincoln). As Ohta-Griliches (1976) showed, the make effects (effects of omitted characteristics on price) of those cars are around .3, which is roughly equal to the estimated coefficient of AC in this study.

(15) The difference in SER between 19720 and 19730 seems to be somewhat larger when make dummies are included (See Table 6).

(16) As shown in Table 1, real gasoline cost was stable during 19760-78A. So it is not clear to us why imputed prices changed significantly in this period.

(17) The Bayesian critical F-value given by (28) is 4.01 for n= 57, k = 24, q = 14. It is 4.61 for n = 120, k = 22, q = 8, and is 5.20 for n = 214, k = 22, q = 6.

(18) (.228 - .198)/(.228 - .182) = .652

Table 1: Consumer Price Index (CPI)

Year·month		All items		Gasoline (Regular and premium)		New car		Used car	
		1957-59 =100	1967=100	1957-59 =100	1967=100	1957-59 =100	1967=100	1957-59 =100	1967=100
69	A	126.4		117.8		101.9		131.2	
	O	129.8		118.0		104.2		125.8	
70	A	134.0		119.2		104.3		121.1	
	O	137.4		119.3		108.7		130.3	
71	A	139.8	120.2	116.0	103.7	108.3	113.8	133.9	109.8
	O		122.6		108.8		115.3		111.7
72	A		124.3		105.0		111.7		106.4
	O		126.2		110.2		110.1		115.2
73	A		130.7		113.8		111.1		117.3
	O		136.6		121.8		111.9		118.5
74	A		144.0		161.4		113.3		110.7
	O		153.2		160.9		123.7		152.3
75	A		158.6		162.8		127.5		138.1
	O		164.6		178.7		129.9		156.5
76	A		168.2		171.2		134.4		159.4
	O		173.3		179.9		139.1		179.9
77	A		179.6		187.0		140.6		187.8
	O		184.5		190.0		145.7		178.0
78	A		191.5		190.1		151.2		177.3
	O		200.9		202.0		155.1		195.4
79	A		211.5		235.4		163.9		200.0
	O		225.4		305.2		167.4		199.9
80	A		242.5		376.3		177.7		196.8
	O		253.9		371.7		182.0		222.7
81	A		266.8		420.8		186.2		239.1

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

Table 2: 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 3a: 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 3b: Consumer Reports' MPG data

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

Table 4: Regression of 1/MPG on physical characteristics (1974 - 78 vintage cars)

Physical characteristics	Estimated coefficient	t-value
Constant	.116E-1	1.954
CID	.179E-3	11.532
NOC	-.185E-2	-2.549
WT	.132E-5	1.042
WBW	.182E-5	1.948
NOD2	.196E-2	1.674
NOD5	.616E-3	.401
AT	.212E-2	1.181
PS	-.385E-2	2.195
AC	-.101E-1	-4.518
No. of obs.	607	
R^2	.681	

Note: See section III and IV for the abbreviations of physical characteristics. E-1 implies the multiplication of 10^{-1} and so on. R^2 is the multiple correlation coefficient squared.

Table 5: Imputed prices of H and CID

Year·month	Vintage used	H		CID	
		Est. coeff.	t-value	Est. coef.	t-value
1970 A	1966-69	*.00094	3.76	*.000018 .000061	.07 .22
73 0	70-72	.00055	1.39	.0014	3.34
76 0	73-75	.0020	4.65	.0029	10.52
80 0	77-79	-.00099	-1.64	.0021 *.00091	4.68 2.82

Note: (1) The table lists OLS estimates of regressing prices on physical characteristics, vintage dummies, constant and occasionally, make dummies.

(2) "Vintage used" column shows the vintages of cars that are used in the estimation.

(3) * --- based on regression with make dummies. Without *, based on regression without make dummies.

Table 6: Test of equality of imputed prices of physical characteristics over time without consideration of gasoline cost

Year·month compared	Vintage of cars used	Testing F-statistic	Degrees of freedom for the F-statistic	SER Unconst.	SER Constrained
1970A,71A	1966-69	*8.21	*19, 452	*.084	*.086
		7.31	7, 476	.123	.124
71A,72A,720	70			*.098	*.097
		5.72	16, 351	.124	.123
72A,720,73A	70,71	8.10	16, 720	.242	.242
720,73A,730	70,71	13.39	16, 720	.247	.249
720,73A	70,71	12.56	8, 480	.244	.246
73A,730	70,71	7.09	8, 480	.245	.250
720,730	70,71	22.89	8, 480	N.C.	N.C.
720,730	67-71			*.205	*.210
		27.16	7, 846	.228	.230
730,74A,740	70-72	55.61	16, 1074	.227	.231
730,74A	"	90.35	8, 711	.2267	.2340
74A,740	"	28.67	"	.229	.229
730,740	"	52.08	"	.225	.228
740,75A,750	70-72	15.12	16, 1074	.234	.235
				**.224	**.224
				**.233	**.236
				**.233	**.238
740,75A	70-72	10.70	8, 716	N.C.	N.C.
75A,750	"	9.00	"		
740,750	"	25.30	"		
750,76A,760	71-74	9.26	18, 1362	.219	.219
				**.210	**.210
				**.215	**.216
				**.224	**.227
750,76A,760	74	4.71	18, 303	.137	.138
760,77A,770	72-75	27.32	18, 1341	.169	.175
760,77A	"	2.58	9, 894	.166	.166
77A,770	"	28.66	"	.176	.176
760,770	"	49.00	"	.165	.176
760,77A	74,75	1.27	9, 434	.156	.155
77A,770	"	12.70	"	.163	.164
760,770	"	27.42	"	.154	.158

(Continue)

Table 6: (Continued)

Year·month compared	Vintage of cars used	Testing F-statistic	Degrees of freedom for the F-statistic	SER	
				Unconst.	Constrained
770,78A,780	72-75	25.53	18, 1341	.195	.209
{ 770,78A	"	43.29	9, 894	.187	.197
{ 78A,780	"	8.39	"	.204	.204
{ 770,780	"	23.59	"	.193	.203
{ 770,78A	74-75	29.83		.172	.188
{ 78A,780	"	8.05	"	.183	.182
{ 770,790	"	11.27	"	.172	.179
780,79A,790	74-77	141.19	18, 1380	.183	.196
{ 780,79A	"	6.20	9, 920	.184	.184
{ 79A,790	"	242.25	"	.187	.201
{ 780,790	"	248.06	"	.179	.200
790,80A,800	74-77	25.81	18, 1380	.198	.212
{ 790,80A	74-78	41.73	9, 1190	.207	.216
{ 80A,800	"	17.49	"	.219	.219
{ 790,800	"	50.32	"	.210	.220
800,81A	75-79	23.50	9, 1256	.201	.202
"	76-79	24.55	9, 1024	.192	.195

Note: (1) Regression equation system is equation (29) of the text.

(2) SER --- Standard error of regression.

(3) * --- Based on regression with make dummies.

(4) ** -- SER unadjusted by degrees of freedom for each year·month in turn in the most left column.

(5) N.C. --- Not calculated, because we do not need these values.

Table 7: Imputed prices of physical characteristics in 1973A-74A (Without consideration of gasoline cost)

Physical characteristics	1973A		1973O		1974A	
	Est. coef.	t-value	Est. coef.	t-value	Est. coef.	t-value
CID	.866E-3	1.595	.133E-2	3.194	.158E-2	3.692
NOC	.250E-1	.876	-.567E-3	-.027	-.185E-1	-.869
WT	.400E-3	3.894	.366E-3	4.991	.274E-3	3.629
WBW	-.271E-3	-5.622	-.273E-3	-8.169	-.320E-3	-9.294
NOD2	.397E-1	.907	.582E-1	1.862	.294E-1	.915
NOD5	-.899E-1	-1.200	-.612E-1	-1.172	-.429E-1	-.799
AT	.172	1.966	.111	1.643	.573E-1	.825
PS	.177	2.032	.142	2.114	.153	2.214
Vintage used	70, 71		70-72		70-72	
No. of obs.	250		369		369	
R^2	.606		.679		.636	

Note: The table lists OLS estimates in the regression with constant and vintage dummies besides the above characteristics.

Table 8: Imputed prices of physical characteristics in 19760-78A

Physical characteristics	19760		1977A		19770		1978A	
	Est. coeff.	t-value	Est. coeff.	t-value	Est. coeff.	t-value	Est. coeff.	t-value
CID	.280E-2	11.347	.290E-2	10.261	.285E-2	10.197	.282E-2	8.897
NOC	-.645E-1	-5.141	-.643E-1	-4.483	-.491E-1	-3.457	-.413E-1	-2.571
WT	.647E-4	2.615	.726E-4	2.566	.639E-4	2.282	.665E-4	2.095
WBW	-.720E-4	-4.694	-.864E-4	-4.925	-.129E-3	-7.428	-.183E-3	-9.318
NOD2	.125	6.682	.134	6.278	.101	4.753	.108	4.495
NOD5	.128E-1	.500	.288E-2	.098	-.329E-1	-1.133	-.530E-1	-1.613
AT	-.118	-2.796	-.151	-3.113	-.158	-3.305	-.180	-3.321
PS	.135	3.349	.163	3.550	.159	3.484	.175	3.389
AC	.247	6.205	.260	5.714	.294	6.533	.316	6.186
Vintage used	72-75		72-75		72-75		72-75	
No. of obs.	460		460		460		460	
R^2	.826		.795		.787		.749	

Note: The table lists OLS estimates in the regression with constant and vintage dummies besides the above characteristics.

Table 9: Imputed prices of physical characteristics in 1979A-80A (Without consideration of gasoline cost)

Physical characteristics	1979A		1979O		1980A	
	Est. coeff.	t-value	Est. coeff.	t-value	Est. coeff.	t-value
CID	.174E-2	5.695	.167E-2	5.766	.184E-2	5.682
NOC	.108E-1	.737	.808E-3	.058	-.279E-1	-.018
WT	-.154E-5	-.067	-.566E-5	-.261	-.121E-5	-.050
WBW	-.840E-4	-4.655	-.176E-3	-10.289	-.208E-3	-10.873
NOD2	.709E-1	3.029	.523E-1	2.349	.447E-1	1.798
NOD5	-.161E-1	-.521	-.508E-1	-1.725	-.121	-3.680
AT	-.101	-2.901	-.120	-3.606	-.146	-3.940
PS	.291	8.496	.274	8.423	.268	7.380
AC	.449	10.040	.474	11.128	.473	9.972
Vintage used	74-77		74-77		74-77	
No. of obs.	473		473		473	
R^2	.773		.776		.744	

Table 10: Test of equality of imputed prices of physical characteristics over time with consideration of gasoline cost

Year·month compared	Vintage of cars used	Testing F-statistic	Degrees of freedom for the F-stat.	S E R	
				Unconstrained	Constrained
1975O, 76A, 76O	1974	2.77	18, 294	.139	.137
76O, 77A	74, 75	.67	9, 426	.156	.155
77A, 77O	"	2.39	"	.162	.166
76O, 77O	"	3.94	"	.153	.157
77O, 78A	74, 75	3.06	9, 426	.168	.171
78A, 78O	"	.63	"	.181	.182
77O, 78O	"	3.19	"	.171	.173
78O, 79A	74-77	3.32	9, 912	.184	.181
79A, 79O	"	11.54	"	.1874	.1938
78O, 79O	"	14.66	"	.179	.185
79O, 80A	74-78	3.56	9, 1180	.202	.204
80A, 80O	"	4.70	"	.211	.211
79O, 80O	"	5.94	"	.203	.204
80O, 81A	76-79	5.74	9, 1014	.187	.190

Note: Regression equation system is equation (30) of the text.

Table 11: Imputed prices of characteristics in 1979A-79O (With consideration of gasoline cost)

Characteristics	1979A		1979O	
	Est. coeff.	t-value	Est. coeff.	t-value
CID	.230E-2	6.603	.201E-2	5.817
NOC	.135E-1	.917	.451E-2	.322
WT	.672E-5	.299	-.293E-6	-.014
WBW	-.983E-4	-4.356	-.151E-3	-4.885
NOD2	.719E-1	2.957	.392E-1	1.754
NOD5	-.132E-1	-.427	-.204E-1	-.655
AT	-.909E-1	-2.437	-.717E-1	-1.939
PS	.309	6.120	.226	4.643
AC	.426	6.730	.355	5.182
$1/(MPG \cdot \hat{P})$	-7703.71	-.873	-14047.8	-1.874
Age of Car/$\hat{P}$	198.84	3.754	89.434	1.734
Age of Car/$(MPG \cdot \hat{P})$	438.524	.228	1127.25	.802
Vintage used	74-77		74-77	
No. of obs.	472		472	
R^2	.785		.790	

Note: OLS estimates in the regression with constant and vintage dummies besides the above characteristics.

Table 12: Test of equality of imputed prices of physical characteristics over time without consideration of gasoline cost (Consumer Reports' sample)

Year·month compared	Vintage of cars used	Testing F-statistic	Degrees of freedom for the F-stat.	SER	
				Unconstrained	Constrained
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	.178
730, 74A	70-72	10.59	8, 98	.143	.152
74A, 740	70-72	9.30	8, 98	.152	.148
740,75A,750	70-72	1.52	16, 147	.155	.148

Table 13: Test of equality of imputed prices of physical characteristics over time with consideration of gasoline cost (Consumer Reports' sample)

Year·month compared	Vintage of cars used	Testing F-statistic	Degrees of freedom for the F-stat.	S E R	
				Unconstrained	Constrained
1970A, 71A	66-69	.97	6, 142	.111	.110
71A,72A,72O	70	.93	14, 24	.090	.080
72O, 73O	67-71	2.94	6, 186	.177	.179
73O, 74A	70-72	1.11	8, 92	.140	.140
74A, 74O	70-72	.48	8, 92	.147	.143
74O,75A,75O	70-72	.26	16, 138	.169	.147

Table 14: Relative estimated qualities among various sizes of cars (%)

Year·month	Vintage	No. of obs.	Full-size/Mid-size A	Full-size/Mid-size B	Mid-size/Compact A	Mid-size/Compact B
1978O	74-77	472	11.3	16.2	2.0	4.0
79A	"	"	12.8	18.3	1.9	4.0
79O	74-78	607	-.1	7.0	-6.0	-1.3
80A	"	"	-2.2	7.0	-7.8	-1.4
80O	"	"	-2.6	9.2	-8.2	1.3
81A	76-79	523	-10.3	9.8	-7.4	.9

Year·month	Compact/Subcompact A		Subcompact A/ Subcompact B		Full-size/Subcompact B	
	A	B	A	B	A	B
1978O	.7	3.1	-.7	1.2	13.3	24.4
79A	1.6	4.3	-.9	.9	15.4	27.6
79O	-13.8	-6.6	-12.2	-5.9	-32.1	-6.7
80A	-17.2	-7.0	-15.1	-6.2	-42.3	-7.6
80O	-17.3	-1.6	-15.4	-1.6	-43.5	7.3
81A	-8.0	2.1	-11.7	-1.2	-37.4	11.6

Note: (1) The number in the column of K/J type shows by how much percent the estimated quality of model K is higher than that of model J.

(2) Column A shows the results using the estimated coefficients of characteristics obtained without considering gasoline cost. Column B shows the results with the consideration of gasoline cost.

(3) The car models that are used as the representatives of various size classes are all of 1975 vintage and are shown in the parentheses below: Full-size (Chevrolet Impala), Mid-size (Chevrolet Cheville Malibu), Compact (Ford Granada), Subcompact A (Ford Mustang) and Subcompact B (Datsun B210). We assumed in the calculation of the table that Mustang had been hypothetically 4-door, because all the other car models above have 4 doors. The characteristics of these models are shown in Table 14A.

Table 14A: Characteristics of car models used in Table 14

Character-istics	Full-size	Mid-size	Compact	Subcompact A	Subcompact B
	Chev. Impala	Chev. Chevelle Malibu	Ford Granada	Ford Mustang	Datsun B210
CID	350	250	200	139	85.3
H	145	105	75	83	80
NOC	8	6	6	4	4
WT	4218	3713	3203	2660	1985
WB	121.5	116	109.9	96.2	92.1
Width	80	77	74	71	61
NOD	4	4	4	2	4
Length	223	210	198	175	163

Note: AT, PS and AC of all the models are 0.