WILLINGNESS TO PAY FOR CAR EFFICIENCY

A Hedonic Price Approach

By Allen C. Goodman*

In the wake of two severe oil price "shocks" in the past decade, automobile efficiency (usually measured in miles per gallon, or MPG) has assumed great importance to buyers. Both the increased cost of gasoline and its sometimes doubtful availability have led, through mandated change and consumer pressure, to the production of cars that are considerably more fuel-efficient than their predecessors. It is useful, in this context, to measure the valuation of this increased efficiency through consumers' willingness to pay for MPG.

This paper applies hedonic price analysis to recent automobile market activity, with special emphasis on the implicit valuation (or hedonic price) of increased MPG. This is a return to an analysis first used by Court (1939) and Griliches (1971), in which the bundle price of a car is expressed as a function of several descriptive dimensions. MPG has generally been inconclusive in these analyses, which all predate the multifold oil price increases of the 1970s.

Four sets of hypotheses are presented and tested with data on two-year-old cars sold in 1977 and 1979. The first considers and rejects coefficient equality over the two years. The second examines use of flexible functional forms of the hedonic regressions; the often-used linear and log-linear forms are examined and found wanting. The third set of hypotheses examines the values of hedonic coefficients, with specific emphasis on MPG; in general, hedonic prices in the 1977 market are consistent with theory, but several in the 1979 market, including MPG, are unstable, switching signs. The fourth examines the elasticity of willingness to pay for increased MPG; for the 1977 market this is approximately –2.0, suggesting a positive, but rapidly decreasing, valuation for additional increments.

The first section of the paper reviews the applicability of hedonic price theory to the automobile market. Section 2 considers the analytics of MPG in a hedonic price function. Section 3 sets out the research design and hypotheses and discusses the data set on used cars. Section 4 presents general findings on the hypotheses, and Section 5 examines willingness to pay for MPG in detail. Section 6 offers conclusions and suggests directions for further research.

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This analysis will consider a car on the used car market. Conceptually this is preferable to the new car market because it is a well-defined regional, if not national, market, and because considerations of discounts and financing should be less important. The value of the *j*th used car should equal the present discounted value of operating benefits, b_{jt}, less the present discounted value of operating costs, c_{jt}, with discount rate r and t varying from 0 to T. For types 1 and 2, the market difference in value, $V_1 - V_2$, should be:

$$V_1 - V_2 = \sum_{o}^{T} \frac{(b_{1t} - b_{2t}) - (c_{1t} - c_{2t})}{(1+r)^t}. \tag{4}$$

Differences in mileage should decrease operating costs, other things being equal. For a given level of benefits, then, the capitalised value of the increased MPG is:

$$V_1 - V_2 = \sum_{o}^{T} \frac{c_{2t} - c_{1t}}{(1+r)^t} \tag{5}$$

The appropriate discount rate r and the useful life of the car should be discussed. Many recent econometric studies on individual consumers have found discount rates of 20 to 25% or more, well above the traditional estimates. Automobile interest rates of over 15% go back to the 1950s (see Katona, 1964), and the existence of viable credit card markets at terms of 18% and over indicate that some marginal decisions are made at discount rates that are as high as that. Uncertainty about product quality may also raise the discount rate. Hausman (1979) concludes that individuals simply behave in a manner which implies a much higher discount rate than can be explained in terms of the opportunity costs of funds available in credit markets.

With respect to the useful life of the car at the time of purchase, most purchasers keep used cars for three to four years, then resell them or scrap them. The median life of a vehicle is ten years—it is plausible to assume that individuals who purchase used cars are aware of this.[4]

Specification of MPG in the hedonic price regression should consider the nonlinearity involved in the cost savings function. Define S as the level of gasoline expenses for a car, z as annual miles travelled, g as mileage per gallon and p as the price of gasoline per gallon. Expenses per period of time can be written as

$$S = zp/g. \tag{6}$$

On the assumption that miles travelled is not responsive to mileage per gallon, the change in expenses is a decreasing function of g,

$$\frac{\partial S}{\partial g} = -zp/g^2. \tag{7}$$

An increase of one MPG decreases gasoline purchases by about 10% at 10 MPG, but by only about 5% at 20 MPG. This suggests that willingness to pay for additional mileage per gallon should decrease with increased MPG.

[3] David L. Greene has been helpful in pointing out this fact.

[4] Both figures are found in Kulp *et al.* (1980), Tables 2.11 and 2.29.

3. RESEARCH DESIGN AND HYPOTHESES

The formal research design considers the used car market in two separate years, 1977 and 1979. The prices of two-year-old car models, collected from the *Red Book,* are linked to variables describing approximately 200 models of domestic and imported cars for each year. These variables have been selected to represent ten types of attributes: (1) reliability, (2) comfort, (3) handling, (4) performance, (5) styling, (6) safety, (7) size, (8) power, (9) load capacity, (10) practicality. The categories are obviously not exclusive; for example turning radius may describe handling, performance or safety. But it is difficult to think of categories that have been omitted. So this study should not suffer, as hedonic price work so often does, from bias arising from omitted variables, which leads in turn to biased parameter estimates. The data are summarised in the Appendix.[5]

It is often necessary to pool observations over years to obtain enough variation to estimate automobile hedonic prices. This constrains relative hedonic prices to be constant, and can be quite restrictive, especially over a long time period. The sample size here allows us to estimate hedonic price functions for the individual years. Appropriate covariance tests compare the coefficients between years.

Two problems arise with the data set. First, the prices are only as good as the source. The *Red Book* has been a traditional reference for used car prices, and would presumably be replaced if it were consistently wrong. On the other hand, its estimates *are* estimates based on recent market conditions. When the market changes dramatically in a short period (for example, in response to oil price shocks), these estimates may be faulty. Also, the automobile components represent components of the new car model year, not necessarily of the used car model year. If, for example, 10% of the 1975 Chevrolets had FM radios, it is assumed that 10% of the two-year-old Chevies also had FM radios. This is probably not exactly true, but the scrappage rate in two years is small across all types of Chevies, and it is not clear that those with FM radios would be more or less likely to be scrapped.[6]

Four types of hypotheses are considered in the empirical analysis.

Coefficient homogeneity. It would be extremely useful for predicting prices if the coefficients were constant from year to year, or differed only by a shift in the constant term. Experience from the housing market suggests that this is not likely; the change in market conditions from 1977 to 1979 was severe, and it is quite likely that many coefficients will have changed in the two years.

Functional forms. Linear, semi-log and log-log forms can be characterised in (λ, δ) space by (1, 1), (0, 1) and (0, 0). The Box and Cox (1964) formulation tests these forms against the more flexible set which allows both λ and δ to vary from -2.0 to $+2.0$.

Variable interpretation. Individual variables should be interpreted and compared with expected signs and magnitudes. In addition, the qualitative "make" and "model"

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[5] This classification of attributes was formulated after extensive consultation with colleagues and with the staff at Oak Ridge National Laboratory. Data were subsequently collected to fill the specifications. The Appendix provides more detail on data preparation. Some of the variables subsequently proved to be collinear, and are therefore dropped from later analysis.

[6] Only four out of 1,000 cars have been scrapped by age 2. See Kulp *et al.* (1980), Table 2.11.

effects can also be tested. Since the primary purpose of the paper is to analyse the willingness to pay for MPG, specific care is given to interpreting this variable.

Willingness to pay. Two-stage procedures are used to calculate consumers' willingness to pay for increased mileage. In conjunction with the associated changes in other components of the automobile package, this can provide indications of the marketability of efforts to conserve energy through increased automobile efficiency.

4. GENERAL FINDINGS

This section summarises findings on the hypotheses discussed above. Each of points (a) through (c) is then discussed in detail. Willingness to pay is considered separately in Section 5.

(a) Covariance tests (*F*-tests) show that variable coefficients differ substantially both in sign and in magnitude between the 1977 and 1979 auto markets. Transfer of one year's regression coefficients to another year can thus provide biased estimates of the underlying parameters.

(b) Linear, semi-log and log-log transformations are all dominated by non-linear functional forms. For 1977 the maximum likelihood values of (λ, δ) are (–1.8, 0); for 1979 they are (–0.6, 0). This suggests that the usual specification of these analyses is inadequate.

(c) Many coefficient estimates change both in sign and in magnitude from 1977 to 1979. The coefficient of chief interest, MPG, shows significant and plausible coefficients for 1977, but it is negative (significantly so) for 1979. No amount of "data mining" can reverse this finding.

(d) Willingness to pay for MPG (for 1977) appears to be fairly responsive to the level of MPG. At the aggregate level, a 1% increase in MPG implies a 1.84% decrease in willingness to pay. For a sample of individual households, a similar increase in MPG implies a 2.17% decrease in willingness to pay.

(a) Coefficient Homogeneity

Hedonic price analysis was originally formulated to show percentage price increases, all else equal, using time dummies. In a market in long-run equilibrium, the prices of various components would stay constant and the coefficients of the dummies could be interpreted as quality-controlled price increases. In particular, the two years compared, 1977 and 1979, were characterised by very different market conditions. In 1977 we had relatively stable, if not falling, oil prices and modest general inflation. In 1979 there had been an oil shortage and oil prices had risen by about 50%, in the face of an inflation rate of over 10%.

The most general formulation pools all the data from the two years into one sample. This imposes the restriction that relative hedonic prices remain constant (see, for example, Goodman, 1978). Second, the R^2, or percentage variance explained, is fairly low; this indicates some difficulty in explaining both years with one structure. A similar regression with a time dummy (all the 1979 observations are deflated by a price index of 1.17) yields insignificant results on the coefficient of the dummy variable.

Table 1 shows the results of the preferred aggregation scheme, separate regressions for the two years. The analysis of covariance to test coefficient equality is an F-test where $F_{35,319}$ equals 7.32. $F_{0.01}$ equals 1.73, so the coefficients are significantly different. These analyses of covariance tests are conducted with specific functional forms, but previous work by the author suggests that such tests are not sensitive to functional form.

(b) Functional Form

After preliminary work to eliminate variables exhibiting either little variation or multicollinearity, a grid search procedure was conducted to maximise the likelihood function of the regressions over the parameters (λ, δ). Previous studies by the author have shown that this function exhibits a single maximum searching over all λ, for δ equal to 1. Varying both λ and δ has led, on occasion, either to multiple maxima or to no maximum at all. In this case, however, maxima are reached for both years.

Estimation of the maximum likelihood function is shown by Zarembka (1974) to be equivalent to an ordinary least squares regression, conditional on (λ, δ). Halvorsen and Pollakowski (1981) present an application of this technique in the housing market, rejecting all the simple functional forms. The following analysis also rejects the forms that have been most generally used.

Maddala (1977) shows that the likelihood functions are directly related to the standard errors of the residuals if the dependent variable is divided by the geometric mean of the sample. Table 2a shows the grid for the 1975 models; Table 2b shows the grid for the 1977 models. Linear regression (i.e. $(\lambda, \delta) = (1, 1)$) is particularly unsuitable; the likelihood statistic is far from the maximum for both years.[7] For the 1975 models, the maximum likelihood estimate of (λ, δ) is (–1.8, 0); for the 1977 models, it is (–0.6, 0). Casual examination of the grids suggests that some search costs can be avoided in future by taking the logarithms of the independent variables and searching only on car price. But further work should probably be done to support this conjecture.

Individual coefficients should be analysed carefully with these functional forms. Halvorsen and Palmquist (1980) point out the pitfalls of uncritically interpreting dummy variables as percentage changes in semi-logarithmic equations, and the problem is similar in this case. Differentiating the hedonic price regression on any continuous variable (let δ equal 1 for simplicity yields $\partial P/\partial x = \beta P^{1-\lambda}$. However, the derivative of the dummy variable does not exist, and Halvorsen and Palmquist show how the change can be approximated with an infinite series expansion. This indicates that the incremental value of the dummy, $P_1 - P_0$, should be evaluated at each value, rather than through the derivative. It can be done with the formulation

$$P_1 - P_0 = [(1 + \lambda\beta/P_0^{\lambda})^{1/\lambda} - 1]P_0, \tag{8}$$

and this is used in subsequent calculations.

[7] Confidence intervals (at the 5% level) for the two years can be calculated by transforming the likelihood functions. For the 1975 models the transformed standard error is 0.1329; for the 1977 models it is 0.0755. Examination of Tables 2a and 2b shows that these confidence intervals rule out most conventional forms.

TABLE 1

1975 and 1977 Hedonic Price Regressions

	1975		*1977*	
LCID	0.139	(0.110)	0.00631	(0.0709)
AC	0.00122	(0.000891)	0.00190	(0.00102)
LOCKS	0.000374	(0.000804)	0.00197	(0.000818)
LINTRM	−0.590	(0.182)	0.750	(0.235)
LPASS	0.221	(0.124)	−0.261	(0.201)
LROOM	−0.235	(0.215)	—	
LTDIA	−0.615	(0.227)	0.518	(0.194)
LWB	1.65	(0.536)	1.59	(0.493)
LWT	−0.548	(0.159)	−0.592	(0.167)
LHP	0.0131	(0.0828)	0.140	(0.0734)
TRUNK	0.000221	(0.000674)	—	
LTANK	—		−0.153	(0.0872)
AM	−0.00160	(0.000673)	−0.00312	(0.000607)
AMFM	0.00236	(0.000888)	0.00494	(0.00133)
STER	0.000869	(0.000839)	0.00163	(0.000835)
LMPGU	0.359	(0.138)	−0.279	(0.118)
LMPGR	0.0782	(0.131)	—	
LMPGH	—		0.0459	(0.133)
WAGON	0.0994	(0.0574)	−0.0667	(0.0589)
MANL	−0.0371	(0.0333)	0.0174	(0.0243)
IM	−8.17	(2.22)	−0.104	(1.63)
GMC	−8.60	(2.22)	−0.257	(1.63)
FORD	−8.53	(2.21)	−0.253	(1.63)
AMC	−8.88	(2.23)	−0.218	(1.61)
CHRYS	−8.64	(2.23)	−0.369	(1.63)
LUX	—		0.193	(0.0475)
SPCL	—		0.0908	(0.0326)
FULL	—		−0.252	(0.903)
MID	—		−0.122	(0.814)
TWO	—		0.723	(0.142)
CMPCT	—		0.00557	(0.0491)
SIX	0.116	(0.0567)	—	
EIGHT	0.173	(0.0881)	—	
BTA	−0.0823	(0.0304)	−0.0125	(0.0241)
WTA	0.107	(0.0322)	−0.0517	(0.0245)
λ	−1.8		−0.6	
δ	0		0	
SER	0.130		0.0739	
#OBS	207		174	
R^2	0.7554		0.8744	

Dependent variable: car price.
Figures in parentheses are standard errors.

TABLE 2

Maximum Likelihood Standard Errors

(a) *1975 Grids*[a]

λ	δ				
	−0.3	0.0	0.2	0.7	1.0
1.0	0.359	0.352	0.366	0.365	0.349[b]
0.7	0.293	0.285	0.282	0.285	0.285
0.2	0.221	0.212	0.210	0.213	0.214
0.0	0.201	0.192[d]	0.191	0.194	0.195[c]
−0.3	0.179	0.169	0.169	0.172	0.174
−0.8	0.156	0.145	0.147	0.149	0.151
−1.3	0.144	*0.1334*	0.136	0.137	0.140
−1.8	*0.140*	0.130*	*0.1331*	0.134	0.137
−2.3	0.142	0.1326	*0.136*	0.137	0.139
−2.8		*0.140*			

(b) *1977 Grids*[a]

λ	δ				
	−0.3	0.0	0.2	0.7	1.0
1.0	0.172	0.142	0.147	0.164	0.168[b]
0.7	0.142	0.113	0.117	0.130	0.134
0.2	0.116	0.0851	0.0898	0.0981	0.102
0.0	0.110	*0.0795*[d]	0.0843	0.0911	0.0951[c]
−0.3	0.104	0.0750	0.0800	0.0847	0.0886
−0.6	*0.101*	0.0739*	*0.0796*		
−0.8	0.101	0.743	0.0793	0.0817	0.0852
−1.3	0.102	*0.0779*	0.0832	0.0838	0.0871

* Maximum likelihood value.
[a] Values in italics lie outside 5% confidence interval.
[b] Linear form. [c] Semi-log form. [d] Log-log form.

(c) Coefficients

Interpretation of individual hedonic price coefficients is often uncertain because of multicollinearity in the variables. Here, in addition, coefficients must be transformed. This section, then, looks at individual coefficients for 1975 models, and then for 1977 models. Special attention is given to the treatment of MPG.

Table 3 lists the hedonic prices of the variables in the 1975 model regression. They are evaluated at the mean variable values, and dummy variables are evaluated as noted above. The regressions are the "weighted least squares" models, where the weights are related to vehicle sales.[8]

[8] It is apparent from the summary statistics (Table A1) that certain models and manufacturers (American Motors, for example) are overrepresented. The weighting provides a more accurate measure of the components on the market.

TABLE 3

1975 and 1977 Hedonic Prices[a] *(incremental values)*

	1975 $	1977 $
CID	5.11	4.60
AC	6.12	—
INTRM	−14.43	10.79
PASS	75.81	−375.79
TDIA	−54.27	−55.43
WB	50.50	—
HP	—	−3.10
AM	−8.36	−11.91
AMFM	9.38	18.64
STER	6.52	9.21
MPGU	93.27	−29.40
WAGON	595.02	—
MANL	−217.45	44.91
GMC	−921.68	−275.23
FORD	−731.07	−341.68
AMC	−1219.51	−671.59
CHRYS	−914.34	−522.03
LUX	—	847.44
TWO	—	453.53
SIX	742.51	—
EIGHT	501.64	—
BTA	−90.26	244.52
WTA	195.44	−99.21

[a] Hedonic prices are calculated at variable means.

The two columns represent the "culled market basket", the regression with those variables with *t*-statistics less than 1 removed. Variables representing size, luxury and safety have the expected positive valuations. An increase of one cubic inch in displacement implies a $5.11 increase in market value; a one-inch increase in wheelbase leads to a $50.50 increase. AM, AMFM, and STEREO have plausible signs; cars that have only AM radios must generally be regarded as of lower quality than those with the classier options. Handling is judged to be important. A one-foot increase in turning diameter leads to a $54.27 fall in value.

For qualitative variables, "make effects" are significant and substantial. Foreign cars command a premium of $731 over Ford products, $922 over General Motors, $914 over Chrysler and $1220 over AMC. These represent mark-ups of approximately 20%. Eight-cylinder models sell for approximately $240 less than six-cylinder models; as Griliches (1971) points out, this probably represents the premise that the eight-cylinder engines provide the same performance, which is held constant, as the six-cylinder models, but at a lower cost per unit of performance.

MPG performs well for the 1975 models. At the mean, approximately 15.6 MPG, the hedonic price of an additional mile per gallon is approximately $93. From the tests derived in (3) the second derivative is negative, implying a decreasing hedonic price. This is consistent with the simple model described in (6) and (7).

It is useful to calculate the implicit discount rate ρ, from the continuous analogue to (4) and (5). Interpret the incremental value, $\partial P/\partial x$, as the integral of the annual savings S *over the future life* T of the car, so that

$$\frac{\partial P}{\partial x} = \int_0^T S e^{-\rho t}\,\mathrm{d}t \tag{9}$$

Given S, and $\partial P/\partial x$, this can be solved for any T to find ρ. Then ρ is transformed into discrete terms.

Published data show the median life of all cars to be 10.0 years. Though used cars are kept for only three or four years, the salvage value at the end of this time should reflect the ten-year life. Hence (9) is evaluated for T equal to 8, as eight years is the expected remaining life of the car, irrespective of owner (see Kulp *et al.*, 1980, Tables 2.11 and 2.29).

Equation (9) is evaluated for S, at the mean MPG of 15.6. From (7), S equals $36.98 $\partial P/\partial x$ *equals* $93.27.[9] The implicit discount rate for S is approximately 0.32. This may seem high, but it may accurately reflect the uncertainty involved in buying a used car. It is certainly consistent with recent estimates of individual discount rates obtained for other durable goods.

The 1977 models have similar hedonic prices for some variables. CID, LOCKS, TDIA and the "radio" variables all exhibit similar magnitudes and signs. It is disturbing that interior room, number of passengers, and percentage with manual transmission, for example, exhibit different magnitudes *and* signs from their 1975 counterparts. Most disturbing is the hedonic price for MPG. Economic theory would predict that it should rise from 1977 to 1979, in accordance with the increased savings attendant on an increase in MPG (because of the higher fuel prices). Not only does it fall, but it is significantly negative.

Repeated attempts to "mine" the data for the correct signs are fruitless, so it is perhaps useful to re-examine some of the assumptions in the model.[10] A hedonic price model requires at least short-run equilibrium in the component markets, and it may well be that the *Red Book* generally represents short-run equilibrium prices in well-behaved markets. The 1979 United States market was subject to substantial oil price hikes and oil supply uncertainty, and both might be expected to have a strong impact on auto demand. The resulting bundle prices may not even represent short-run equilibrium, and the imputed hedonic prices may be similarly difficult to interpret. Re-estimation of the equations for intervening (or subsequent) years may provide some indication of how serious this instability is.

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[9] This assumes 15,000 miles driven per vehicle, with the price of gasoline as 60 cents per gallon.

[10] Several treatments were used to try to "mine" the data for the right sign. These included several types of principal components analyses that are often useful for data that exhibit multicollinearity. The gruesome story is available from the author on request.

5. WILLINGNESS TO PAY FOR MPG

The hedonic price function represents market information on both supply and demand for a given bundle component. Given the first-stage estimation of the function, the second stage of the technique is to identify the implicit demand and supply functions. Demand theory indicates that the demand price, or willingness to pay, for a certain amount of the component is a function of the income y_i and other household variables v_i, which influence tastes or preferences. The observed hedonic price, $\partial P/\partial x_i$, is taken to be a measure of willingness to pay, w_i, or:

$$w_i = w_i\,(x_i, y_i, v_i). \tag{10}$$

It can be argued that the supply of individual models of two-year-old cars is exogenous (or "fixed") in the short term. Clearly, the specific year's models are no longer being built. If new cars are regarded as substitutes for two-year-old cars, there may be a supply relationship between the hedonic price and MPG.[11] If there is an increase in the number of cars in the market with high MPG, this will lower their price in comparison with other types of cars, and will also lower the marginal implicit value of MPG derived from the hedonic price regression. However, recent experience in the international market suggests that U.S. manufacturers are constrained from being very responsive to the need for more fuel-efficient cars. Moreover, new cars (at the time) constituted less than 10% of the auto stock each year, and it is hard to attribute a large portion of that to responsiveness to the hedonic price of MPG. It is plausible, then, to treat supply of MPG as exogenous in the short run; more explicit treatment may be necessary for long-run analysis.

The inverse demand function is derived from (6) and (7). Successive incremental increases in MPG provide smaller decreases in gasoline purchases. This is consistent with the negative second derivatives from the flexible functional form, which suggests that the envelope of the supply-demand interactions in $(x_i,\ \partial P/\partial x_i)$ space is downward-sloping. It would not occur, however, if the hedonic regression were constrained to semi-log form, for example, as this would imply that the equilibrium valuation of MPG would rise with an increase in MPG.

With these characterisations of supply and demand, two bases are used to identify willingness to pay:

1. The market hedonic price relationship itself, with an attempt to infer willingness to pay at the "model" level.
2. The behaviour of individual households owning 1975 cars in 1977.

Both analyses indicate that willingness to pay is very responsive to changes in the level of MPG: a 1% increase in MPG leads roughly to a 2% fall in willingness to pay.

Table 4 shows a regression of $\partial P/\partial \mathrm{MPG}_i$ against MPG_i for 1975 models (both terms in logarithms). The regressions fit fairly well for domestic models ($R^2 = 0.62$), but considerably less well for imports ($R^2 = 0.08$). For domestic models, a 1%

[11] It might also be argued that increases in the hedonic price of MPG may cause the abandonment of "clunkers", those cars that are already marginal. It is not clear how much impact this response might have on how it might be measured.

TABLE 4

Willingness-to-Pay at the Model Level

Subgroup	*All*	*Domestic*	*Imports*
Dep. Var.	LOG (hedonic price)	LOG (hedonic price)	LOG (hedonic price)
Constant	9.30 (0.574)	12.1 (0.500)	10.1 (2.75)
LMGU	−1.84 (0.211)	−2.99 (0.191)	−1.96 (0.915)
R^2	0.2699	0.6196	0.0798
S.E.R.	0.853	0.561	1.18

Figures in parentheses are standard errors.

increase in MPG implies a 3% decrease in willingness to pay. The same percentage increase for imports yields about a 2% decrease. The pooled regression implies a 1.84% decrease for each 1% increase in MPG.

These figures probably represent underestimates of the elasticity (with corresponding overestimates of the implied demand elasticities). If, for example, vehicle miles travelled (z in equation (7)) are responsive to MPG (people who drive more choose more efficient cars), the higher value of z implies a higher marginal valuation, or willingness to pay.[12]

Estimates at the household level may provide further information. The presumption here is that households constantly re-evaluate their choice of car *vis-à-vis* the numerous dimensions and associated hedonic prices. With a specific MPG, a household will keep the car if its willingness to pay is greater than provided by the market. If it is less than the market's implicit price, the household could sell the car and purchase another, similar but with lower MPG. The various "shift parameters" available at the household level suggest that it might be possible to sharpen estimates of individual willingness to pay over the "model regression".

A sample of households was chosen from the Baltimore Disaggregate Dataset to test this assumption. Eighty-two households, interviewed in the summer of 1977, owned 1975 model cars that were identifiable from the hedonic price data. MPG and the associated hedonic price were assigned to individual households.[13] Explanatory variables in the willingness-to-pay function are: PERS, number of persons in the household; VEHCL, number of vehicles in the household; DPUB, distance (in blocks) to the nearest public transport; DART, distance (in blocks) to the nearest artery;

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[12] Differentiating (6) totally yields

$$\frac{dS}{dg} = -(zp/g^2) + \frac{p}{g}\frac{dz}{dg}.$$

If dz/dg is positive, as noted in the text, the implied willingness to pay increases.

[13] Ten households were subsequently dropped because data were inadequate. See the Appendix for a more thorough description of the Baltimore Dataset.

TABLE 5
Willingness to Pay at the Household Level

DEP. VAR.	*LOG (Hedonic Price)*		*Hedonic Price*	
CONSTANT	11.2	(2.25)	5.63	(0.463)
PERS	0.0319	(0.0475)	0.0369	(0.0497)
VHCL	0.0446	(0.0949)	−0.0106	(0.104)
DPUB	−0.00860	(0.0156)	−0.00987	(0.0164)
DART	0.0523	(0.0246)	0.0425	(0.0288)
DEXP	0.0341	(0.0363)	0.0393	(0.0382)
LINC	−0.155	(0.200)	0.351E−05	(0.104E−04)
CCITY	0.455	(0.197)	0.508	(0.205)
LMPGU	−2.17	(0.317)	0.121	(0.0207)
R^2	0.47		0.42	
S.E.R.	0.729		0.765	

Figures in parentheses are standard errors.

DEXP, distance (in miles) to the nearest expressway; INC, household income; CCITY, 1 if the residence was in the central city, 0 otherwise.

DPUB, DART, and DEXP should have positive signs, implying more savings with an increase in MPG. PERS implies more use, and thus a positive sign; VEHCL implies less use, and so a negative. If MPG is a normal good, the sign on INC should be positive. No prior reasoning can determine a sign for residential location independent of income and distance.

Two regressions are presented in Table 5. Care should be taken in interpretation, since only a subset of the models available is used in the analysis. As is shown in Figure 1, willingness to pay appears to be slightly more elastic than in the "model" case (−2.17 versus −1.84). It is responsive to distance both from arterial and from expressway roads, and in the former case to a statistically significant degree. Income gives the "wrong" sign in one of the regressions; so does VEHCL. CCITY is positive and significant in both regressions.

The results suggest that the "model" regression is a reasonable proxy for estimates at the household level. In both cases the willingness to pay is responsive to MPG: alternatively, the implied demand for MPG is relatively inelastic. This inelasticity indicates that uncritical extrapolation of a point estimate of willingness to pay, to an increased (mandated, for example) level of MPG, will lead to an overestimate at the aggregate level.

More specifically, consider a policy aimed at increasing mean MPG from 15.6 to 20. Extrapolation of the $93 estimate (that is treating it as a constant) suggests an incremental willingness to pay of approximately $409 for this change. The estimated willingness-to-pay function, however, suggests an incremental value of $325. Here the erroneous extrapolation leads to a 26% overestimate.

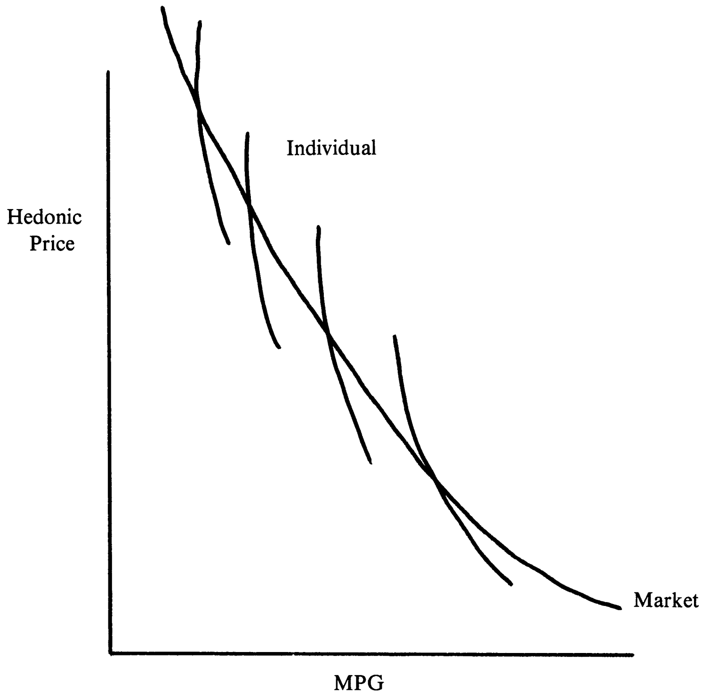

FIGURE 1

Market and Individual Willingness to Pay for MPG

6. CONCLUSIONS

This paper represents an effort both to update automobile hedonic price analysis since the oil price shocks of 1973–74 and 1978–79, and to examine in more detail the hedonic price of MPG. The results are chequered—data for two-year-old 1975 models provide good results, but data for two-year-old 1977 models are less encouraging.

There are four main findings:

(a) Hedonic price regressions can be well estimated from *Red Book* price data, particularly for the 1975 models. These models show good coefficient estimates, with good explanatory power in the regression. The 1977 models yield regressions with better explanatory power, but several variables fare less well. It may be that the *Red Book* represents equilibrium prices in well behaved markets. If the 1979 market for two-year-old cars was not well behaved, the prices listed may not represent the short-run equilibrium prices necessary for estimating hedonic prices.

(b) Separate regressions should be estimated for separate years, and with functional forms that allow flexibility in the resulting envelopes of hedonic prices. In this perspective, earlier analyses may have been limited by restrictions imposed by the choice of functional form.[14]

(c) MPG performs well for two-year-old 1975 models, but poorly for two-year-old 1977 models. For the former set, the best estimate for an implied discount rate is 0.32. This is consistent both with theory and with recent studies examining the discount rates for consumer durables. No truly satisfactory reason can be given to explain the poor performance of MPG for the two-year-old 1977 cars.

(d) Willingness to pay for MPG decreases by about 2% for each 1% increase in MPG. Given the mean value of $93 at mean MPG from the 1975 regression, this implies a fall to $59 for an increase of mean MPG to 20. Uncritical extrapolation of the average figure, here, leads to an *over-estimate* of the aggregate willingness to pay by approximately 26%. As stated above, the data for 1977 models do not provide the parameters necessary for making the same calculation.

These findings should be re-estimated with more recent data to check stability of the coefficients (and of the *Red Book* prices). Further work on more recent data would also provide a means of replicating the multi-year work of Griliches in the late 1960s and early 1970s.

Two other extensions might be useful. Data on mean characteristics for purchasers of different car models would allow more explicit modelling of willingness to pay at the individual level. These models could be used to provide a more thorough test of individual willingness to pay than was permitted by the Baltimore Dataset. Second, there must be more examination of the supply of used cars. Fleet owners, who supply a large proportion of used cars, apparently put them on the market irrespective of their relative prices after a certain period of time. If individual owners operate in the same manner, the supply is probably very inelastic with respect to the implicit price of MPG or any other component. Future research should look into this in more detail.

APPENDIX

Data

The data were collected on a sample of the car models offered for sale by domestic and foreign manufacturers in 1975 and 1977. These data comprised the following 35 variables:

[14] Griliches and his collaborators, for example, have limited their analyses to logarithmic forms.

CID[a]	Cubic inch displacement
AC[b]	Percent cars having air conditioning
LOCKS[b]	Percent cars having power locks
PASS[a]	Number of passengers car can carry
ROOM[a]	Roominess factor
TDIA	Turning diameter (feet)
INTRM[a]	Interior room
WB[a]	Wheelbase (inches)
WT[a]	Weight (pounds)
HP[a]	Horsepower
TRNK[a]	Trunk space
AM[b]	Percent cars having AM radio
AMFM[b]	Percent cars having AMFM radio
STER[b]	Percent cars with stereo
MPGU[a]	Miles per gallon, urban
MPGR[a]	Miles per gallon, rural
MPGH[a]	Miles per gallon, highway
WAGON[a]	= 1 if car is a wagon
MANL[a]	= 1 if car has manual transmission
IM[a]	= 1 if car is an import
GMC[a]	= 1 if car is a GM product
FORD[a]	= 1 if car is a Ford product
AMC[a]	= 1 if car is an AMC product
CHRYS[a]	= 1 if car is a Chrysler product
BTA[c]	= 1 if car is rated better than average
WTA[c]	= 1 if car is rated worse than average
SIX[a]	= 1 if car has a six-cylinder engine
ATE[a]	= 1 if car has an eight-cylinder engine
LUX[a]	= 1 if car is classified "luxury"
SPCL[a]	= 1 if car is classified "special"
TWO[a]	= 1 if car is a two-seater
FULL[a]	= 1 if car is a full-sized model
MID[a]	= 1 if car is an intermediate
CMPCT[a]	= 1 if car is a compact model
MINI[a]	= 1 if car is a "mini" model

An L prefix indicates that the variables are in natural logarithms.
[a] From Chilton's *Automobile Characteristics Data Base.*
[b] From Ward's *Automotive Yearbook.*
[c] From *Consumer Reports Buying Guide.*

The variables summarising mileage per gallon (MPG) are the EPA ratings. The quantity of each model produced was obtained from the annual almanac issue of *Automotive News*.

Two- year-old car prices were calculated for each model on the basis of the average

REFERENCES

Box, G. E. P., and D. R. Cox (1964): "An Analysis of Transformations". *Journal of the Royal Statistical Society,* B26: 211–243.

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,* 14A: 367–378.

Court, A. T. (1939): "Hedonic Price Indexes with Automotive Examples". In *The Dynamics of Automobile Demand.* General Motors, New York.

Freeman, A. M. (1979): "The Hedonic Price Approach to Measuring Demand for Neighbourhood Characteristics". In D. Segal (ed.): *The Economics of Neighbourhood.* Academic Press, New York.

Goodman, A. C. (1978): "Hedonic Prices, Price Indices and Housing Markets". *Journal of Urban Economics,* 5: 471–484.

Griliches, Z. (1971): "Hedonic Prices Revisited". In Z. Griliches (ed.): *Prices Indexes and Quality Change.* Harvard University Press.

Griliches, Z., and M. Ohta (1976): "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis". In N. Terleckyj (ed.): *Household Production and Consumption.* Columbia University Press.

Halvorsen, R., and R. Palmquist (1980): "The Interpretation of Dummy Variables in Semilogarithmic Equations". *American Economic Review,* 70: 474–475.

Halvorsen, R., and H. O. Pollakowski (1981): "Choice of Functional Form for Hedonic Price Equations". *Journal of Urban Economics.* 10: 37–49.

Hausman, J. A. (1979): "Individual Discount Rates and the Purchase and Utilisation of Energy-Using Durables". *Bell Journal of Economics,* 10: 33–54.

Katona, G. (1964): *The Mass Consumption Society.* McGraw-Hill, New York.

Kulp, G., D. B. Shonka, M. J. Collins, B. J. Murphy and K. J. Reed (1980): *Transportation Energy Conservation Data Book.* National Technical Information Service, Virginia.

Lapham, V. (1971): "Do Blacks Pay More for Housing"? *Journal of Political Economy,* 79: 1244–1257.

Maddala, G. S. (1977): *Econometrics.* McGraw-Hill, New York.

Manski, C. F., and L. Sherman (1980): "An Empirical Analysis of Household Choice among Motor Vehicles". *Transportation Research,* 14A: 349–366.

Rosen, S. (1974): "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition". *Journal of Political Economy,* 82: 34–55.

Zarembka, P. (1974): "Transformation of Variables in Economics". In P. Zarembka (ed.): *Frontiers in Econometrics.* Academic Press, New York.