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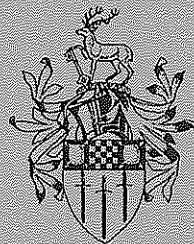
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The Demand for Car Fuel Efficiency: An Hedonic Price Approach

Robert Witt

October 1994



SEEDS 77
ISBN 1-85237-143-9

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University of Surrey

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** The author would like to thank Gop Menon for excellent research assistance.*

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JEL Classification D12 R40

ISBN: 1-85237-143-9

British Library Cataloguing-in-Publication Data.

A catalogue record for this book is available from the British Library.

ABSTRACT

This paper uses an hedonic price approach to estimate the effect of petrol price changes on fuel efficiency and other attributes using data for new cars in the UK. In contrast with Atkinson and Halvorsen (1984), the long-run petrol price elasticity of demand for fuel efficiency is very small, suggesting that the long-run own-price elasticity of demand for petrol is less than unity. The results imply that the adjustment process within the new car market permits little substitution for more fuel efficient cars in response to petrol price changes.

INTRODUCTION

Under the Rio Framework Convention on Climate Change, the UK Government is committed to increase road fuel prices in real terms in order to reduce fuel consumption and, therefore, CO₂ emissions. This policy may have an effect in different ways. One possibility is to encourage consumers to purchase more fuel efficient cars. However, fuel efficiency is only one of a set of car attributes. When a consumer buys a car, he jointly purchases a wide collection of attributes, such as, size, space, performance, engine capacity and fuel efficiency, at a single purchase price. Thus, a consumer that is trying to decide whether to invest in a particular car will take into account the trade-off between fuel efficiency and other attributes. For example, if fuel economy is desirable, then for a given engine technology it is achieved in part by reducing the weight and size of a vehicle, which, in turn, reduces safety.

The general idea of measuring the sensitivity of consumers' demands for different types of cars to changes in petrol prices, has commanded considerable empirical interest in the past (see, for example, Blomqvist and Haessel (1978) and Greenlees (1978)). A more recent study by Ohta and Griliches (1986) examined the impact of energy price changes on the implicit valuation of car attributes, using hedonic regressions. They showed that for US used car data over the period 1966 to 1980, excluding petrol costs, attribute coefficients changed over time, especially during the oil shock periods 1973 and 1979. However, if fuel consumption efficiency variables are added to a more general hedonic price equation, then the estimates of the remaining attributes remained

constant. In other words, consumers in the used car market responded significantly to increases in petrol prices.

Unfortunately formulating the problem in this fashion for new cars has not met with a great deal of success empirically (see, for example, Hogarty (1975)). This is due to a number of factors, not the least of which is the strong collinearity between fuel efficiency and other attributes. This problem was emphasized by Atkinson and Halvorsen (1984) using US data for 158 new 1978 cars: when attributes are determined by a common set of physical characteristics, strong linear dependencies exist.

Atkinson and Halvorsen examine a two equation model. First, estimates of positive shadow prices of attributes (other than fuel efficiency) are obtained. In their model, car price is a function of style, acceleration, comfort of ride, front seat comfort and dummy variables for imported, specialty and luxury cars. This price equation can be considered a reduced form specification, where demand and supply characteristics of the relevant market are included as explanatory variables. Second, a fuel efficiency function is estimated which includes the same attributes as in the price equation. It is assumed that an increase in a desired attribute will decrease fuel efficiency, other things held constant. Atkinson and Halvorsen derive an estimate of the marginal implicit price of fuel efficiency, and together with the hedonic price and fuel efficiency coefficients, provide estimates of the effects of petrol price on the demand for car attributes and fuel efficiency. Using a comparative statics analysis of the utility maximization problem, they found that the main effects of an increase in petrol price are to decrease the demand for styling

while increasing the demand for front seat comfort and fuel efficiency. A similar exercise is performed in this paper to ascertain whether higher petrol prices affect the demand for car fuel efficiency. The model is estimated using a cross-sectional sample of 203 new cars which were available in the UK in 1991.

The paper is organized as follows. Section I presents the theoretical description of the model. Section II details the data and functional form employed, and the results are summarized in sections III and IV. Section V provides conclusions.

I. THE MODEL

The theoretical model presented here is based on the approach of Atkinson and Halvorsen (1984) and Ohta and Griliches (1986). These studies invoked a two-stage hypothesis consisting of two groups of car attributes, those that enter the utility function directly and those that enter the budget constraint. The essence of the hypothesis is that the utility a consumer derives from car ownership depends on car attributes, such as, performance and engine size and not on the amount of petrol purchased. As a result, fuel efficiency (miles per gallon) does not affect utility directly but influences consumers' decisions because it partly determines the cost of using a car.

In modelling systems of demand equations in a static context it is usual to assume weak separability in the utility function of the form:

$$u = F\{U(q), X\} \quad (1)$$

where $U(q)$ is a sub utility function associated with cars, q is an n -component vector of car attributes, other than fuel efficiency, and X is a vector of all other goods. The consumer is assumed to maximize the sub utility function subject to the following budget constraint,

$$Y = V(q) + \sum_{t=1}^T \frac{1}{(1+r)^t} P_t^e M_t E^{-1}(q) \quad (2)$$

where Y is the present value of the budget expenditure on car services over the life of the car, $V(q)$ is the price of the car, r is the discount rate, P_t^e is the expected real price of petrol in year t , M_t is the number of miles travelled in year t , $E(q)$ is the car's fuel efficiency expressed as miles per gallon and T is the

expected lifetime of the car. Other fixed costs, such as, car insurance and road tax are ignored. Similarly, no account is taken of the rate of depreciation.

The consumer's choice problem of car attributes corresponds to the langrangian,

$$L\left(\frac{\partial L}{\partial q_i}, \frac{\partial L}{\partial \lambda}\right) = U(q) + \lambda \left[Y - V(q) - \sum_{t=1}^T \frac{1}{(1+r)^t} P_t^e M_t E^{-1}(q) \right] \quad (3)$$

$$i = 1, \dots, n,$$

where λ is the Lagrange multiplier on the constraint that the sum of car expenditures equals Y . The first-order conditions from (3) are,

$$\frac{\partial L}{\partial q_i} = \frac{\partial U}{\partial q_i} - \lambda \left[\frac{\partial V}{\partial q_i} - \sum_{t=1}^T \frac{1}{(1+r)^t} P_t^e M_t E^{-2} \frac{\partial E}{\partial q_i} \right] = 0$$

$$i = 1, \dots, n, \quad (4)$$

$$\frac{\partial L}{\partial \lambda} = Y - V - \sum_{t=1}^T \frac{1}{(1+r)^t} P_t^e M_t E^{-1} = 0 \quad (5)$$

Equation (4) has the simple interpretation that the marginal utility of each attribute is equal to the marginal capital costs plus the present discounted value of marginal petrol costs.

In carrying out a comparative static analysis of the effect of petrol prices on the equilibrium values of attributes, the second order partial derivatives with respect to car attributes have a useful role to play. Differentiating with respect to the base period price of petrol, P_0^e , and arranging in matrix form, we have

$$\begin{bmatrix}
 Q_{11} & \dots & Q_{1n} \\
 \vdots & & \vdots \\
 Q_{n1} & \dots & Q_{nn} \\
 \phi E_1 - V_1 & \dots & \phi E_n - V_n \\
 \phi E_1 - V_1 & \dots & \phi E_n - V_n \\
 0 & & 0
 \end{bmatrix}
 \begin{bmatrix}
 \frac{\partial q_1}{\partial P_0^e} \\
 \vdots \\
 \frac{\partial q_n}{\partial P_0^e} \\
 \frac{\partial \lambda}{\partial P_0^e}
 \end{bmatrix}
 =
 \begin{bmatrix}
 -\lambda E_1 \frac{\partial \phi}{\partial P_0^e} \\
 \vdots \\
 -\lambda E_n \frac{\partial \phi}{\partial P_0^e} \\
 E \frac{\partial \phi}{\partial P_0^e}
 \end{bmatrix}
 \quad (6)$$

where $Q_{ij} = U_{ij} - \lambda(V_{ij} - \phi E_{ij} + 2\phi E^{-1} E_i E_j)$, $i, j = 1, \dots, n$.

The subscripts on U, V and E represent first and second order partial derivatives with respect to car attributes and

$$\phi = \sum_{t=1}^T \frac{1}{(1+r)^t} P_t^e M_t E^{-2} \quad (7)$$

The scalar ϕ is the marginal benefit of fuel efficiency. It is, of course, equal to the negative of the partial derivative of the total present value of petrol expenditures with respect to fuel efficiency. Thus, $\partial\phi/\partial P_0^e$ is the effect on the marginal benefit of fuel efficiency of a change in the base period price of petrol.

Solving for $\partial q_i / \partial P_0^e$, $i=1, \dots, n$, and given an appropriate form for the sub utility function U, we obtain estimates of the effect of changes in optimal quantities of attributes that result from changes in petrol prices. If we assume that fuel efficiency is determined by the same attributes that appear in the price equation, then we can compute the partial derivative of fuel efficiency with respect to a change in the base period price of petrol, $\partial E / \partial P_0^e$, as

$$\frac{\partial E}{\partial P_0^e} = \sum_{i=1}^n \frac{\partial E_i}{\partial Q_i} \frac{\partial Q_i}{\partial P_0^e} \quad (8)$$

(Atkinson and Halvorsen (1984), discuss the justification for this assumption. In particular, note that the elasticity of demand for fuel efficiency with respect to the price of petrol is calculated without invoking data on fuel prices over time.)

Two observations are in order. Firstly, since there are no available data on fuel-saving technology in cars, we concentrate on the trade-off between attributes and efficiency. In this model, increased fuel efficiency can only occur by decreasing one or more of the car attributes that provide satisfaction from car ownership. Secondly, it is assumed that miles travelled (M_t) is exogenous. Distance travelled is probably influenced by changes in attributes, the capital cost of the car and the price of petrol. This type of model has been frequently analysed in the literature (for example, see Newbery (1992)).

II. DATA AND FUNCTIONAL FORM

The data for this work are for 203 new cars with petrol engines which were on sale in the UK in 1991. The sample is relatively comprehensive and includes at least one variant of each of the top twenty new car registrations for 1991. All types of cars were included by 30 different manufacturers: hatchbacks, saloons, estates, coupes and 4 x 4's. Data on car attributes, such as, size of car, performance, engine capacity and fuel economy were obtained from the Guinness World Car Record (1992). The prices of new cars were taken from Autocar & Motor magazine (various issues), where the lowest and highest price in the sample is £5674 and £35750.

Table 1 reports summary statistics of the information on the 203 cars in the sample. Although data on attributes of acceleration and wheelbase are readily available, we eliminated such variables from the analysis as they measure the same attributes as performance and size¹. For example, the horse power to weight ratio (performance) can bear a direct relationship to the accelerative power of a car. Given many of the included models are luxury high-priced cars, dummy variables are included to pick up the prestige associated with Audi, Bmw, Mercedes, Saab and Volkswagen. Unfortunately, no data series for comfort of ride, front leg room, rear leg room and shoulder room is available, so one possible measure will be tried; the size of car (see Data Appendix).

Table 1
Summary Statistics

Variable	Mean Value	Standard Deviation
Price (£)	15406	6029.50
Fuel Economy (MPG)	26.93	5.21
Engine Capacity (CC)	1901.30	578.43
Brake Horse Power (BHP)	122.60	44.71
Weight (lbs)	2540.10	546.84
Performance ((BHP/Weight)*2240)	106.77	29.39
Length (inches)	167.16	15.12
Width (inches)	67.07	4.06
Height (inches)	54.66	3.58
Size (cubic inches)	615990	99588
Audi (1 = yes)	0.049261	-
Bmw (1 = yes)	0.029409	-
Merc (1 = yes)	0.009852	-
Saab (1 = yes)	0.034483	-
Vw (1 = yes)	0.049261	-
203 observations on new cars		

In the hedonic price literature the empirical specifications are typically derived by using the Box-Cox (1964) methodology. We use this approach and assume that the market price and fuel efficiency relationships are of the form

$$V^{(\lambda)} = \alpha_0 + \sum \alpha_i Q_i^{(\lambda)} + \sum \alpha_j d_j + u \quad (9)$$

$$E^{(\omega)} = \beta_0 + \sum \beta_i Q_i^{(\omega)} + \varepsilon \quad \begin{matrix} i=1, \dots, n \\ j=1, \dots, m \end{matrix} \quad (10)$$

where the α 's and β 's are parameters, d 's are dummy variables for luxury cars, (λ) and (ω) are defined as the transformations

$$\begin{aligned} V^{(\lambda)} &= (V^\lambda - 1)/\lambda & \lambda \neq 0 \\ &= \log V & \lambda = 0 \end{aligned} \quad (11)$$

$$\begin{aligned} E^{(\omega)} &= (E^\omega - 1)/\omega & \omega \neq 0 \\ &= \log E & \omega = 0 \end{aligned} \quad (12)$$

and u and ϵ are random disturbance terms. The maximum likelihood estimates of both λ and ω are equal to zero, implying a double logarithmic functional form.² Thus, the following log-linear regression equations are estimated

$$\log V = \alpha_0 + \sum \alpha_i \log q_i + \sum \alpha_j d_j \quad (13)$$

$$\log E = \beta_0 + \sum \beta_i \log q_i \quad \begin{matrix} i=1, \dots, n \\ j=1, \dots, m \end{matrix} \quad (14)$$

The estimated coefficients of the attribute variables in the sub utility function $U(q)$ are equal to their constant expenditure shares. The sub utility function can be represented by Cobb-Douglas preferences as:

$$\log U = \gamma_0 + \sum_{i=1}^n \gamma_i \log q_i, \quad \begin{matrix} i=1, \dots, n \\ j=1, \dots, m \end{matrix} \quad (15)$$

$$\gamma_i > 0, \quad \sum \gamma_i = 1$$

The normalization rule that $\sum \gamma_i = 1$ is convenient in that we can interpret γ_i as constant budget shares. These are calculated from from equation (13), where $\gamma_i = \alpha_i / \sum \alpha_i$.

III. EMPIRICAL RESULTS

The empirical results presented in this paper will be based on the estimation of equations (13) and (14). Using the variables defined in Table 2, OLS estimates are given in Table 3.

Table 2
Variable Definitions*

Model	Regression	
V	LPRICE	Log (car price)
E	LFUEL	Log (fuel efficiency)
q ₁	LENGINE	Log (engine capacity)
q ₂	LPERFORMANCE	Log (power/weight)
q ₃	LSIZE	Log (length x width x height)
d ₁	Audi	= 1 if Audi; 0 otherwise
	Bmw	= 1 if Bmw; 0 otherwise
	Merc	= 1 if Mercedes; 0 otherwise
	Saab	= 1 if Saab; 0 otherwise
	Vw	= 1 if Volkswagen; 0 otherwise

*

See Data Appendix for sources

Table 3

OLS Equations for Price and Fuel Efficiency

(Standard errors in brackets)

Dependent Variable:	LPRICE	LFUEL
Constant	-7.4184** (1.0242)	9.7920** (0.7510)
LENGINE	0.6158** (0.0628)	-0.3003** (0.0466)
LPERFORMANCE	0.5828** (0.0548)	-0.2727** (0.0410)
LSIZE	0.7236** (0.0904)	-0.2250** (0.0668)
Audi	0.1260** (0.0456)	-
Bmw	0.1452** (0.0511)	-
Merc	0.1863* (0.0987)	-
Saab	0.1513** (0.0549)	-
Vw	0.0664 (0.0454)	-
\bar{R}^2	0.8776	0.6926
σ	0.1382	0.1051
N	203.0	203.0
Reset (χ_1^2)	6.9450**	0.0147
Breusch-Pagan Test (χ_{k-1}^2)	12.9281	4.4314
Normality (χ_2^2)	0.4292	4.9648*

* and ** denote statistical significance at the 10% and 5% level respectively using a two-tailed test.

From column 1 in table 3 we can see that the adjusted R^2 is 0.8776, indicating that around 88% of the variation in price is explained by three explanatory variables and five dummy variables for luxury models. All of the attribute variables are statistically significant at the 5% level. As the equation is estimated in double-logarithmic form, the coefficients on engine, performance and size, can be interpreted as estimates of shadow price elasticities. For example, a 10% increase in the size of a car leads to an implicit 7% increase in price. All the dummy variables are highly significant except in one case, Volkswagen. The coefficients on the dummy variables represent the additional mark-up that consumers are willing to pay for that particular make relative to all other (average) cars in the sample. As an illustration, consumers were willing to pay an additional 20.4% if the car was a Mercedes Benz.

Column 2 in table 3 presents the shadow price of each attribute with respect to fuel efficiency. The coefficients of all the explanatory variables are highly significant and correctly signed. The elasticity of engine capacity is -0.3, suggesting that a 1% increase in engine size causes a 0.3% reduction in fuel efficiency. The importance of car engine size in determining car fuel efficiency has recently been analysed by Sorrell (1992).

The Lagrange Multiplier diagnostic tests for mis-specification, heteroscedasticity and normality are reported in order to assess the adequacy of the estimated models. Given the use of cross-sectional data, the potential problem of heteroscedasticity cannot be ignored. In the price and fuel efficiency equations the 5% critical values are 15.51 and 7.82 respectively, and the null

of homoscedastic errors is not rejected in either equation. However, the mis-specification test in the price equation and the test for non-normal residuals in the fuel efficiency equation detect departures from the classical assumptions.

IV. ESTIMATED PETROL PRICE ELASTICITIES OF DEMAND

Given the above results concerning the shadow price estimates, attention turns to the elasticities of demand for car attributes and fuel efficiency with respect to the price of petrol. Allowing for three attributes ($q_i = 1, 2, 3$), the derivatives in (6) may be construed in the following terms:

$$1. \quad V_i = \frac{\partial V}{\partial q_i} = \frac{\partial \log V}{\partial \log q_i} \frac{V}{q_i} = \frac{\alpha_i V}{q_i}$$

$$V_{ij} = \frac{\partial^2 V}{\partial q_i \partial q_j} = - \frac{\alpha_i V}{q_i^2} \quad i = j$$

$$= 0, \quad i \neq j$$

$$2. \quad E_i = \frac{\partial E}{\partial q_i} = \frac{\partial \log E}{\partial \log q_i} \frac{E}{q_i} = \frac{\beta_i E}{q_i} \quad (16)$$

$$E_{ij} = \frac{\partial^2 E}{\partial q_i \partial q_j} = - \frac{\beta_i E}{q_i^2} \quad i = j$$

$$= 0, \quad i \neq j$$

$$3. \quad U_{ij} = \frac{\partial^2 \log U}{\partial q_i \partial q_j} = - \frac{\gamma_i}{q_i^2} \quad i = j$$

$$= 0, \quad i \neq j$$

To obtain values of the remaining terms in (6) (ϕ and λ) requires explicit assumptions about discount rates, car life expectancies, annual mileage and expectations of petrol prices. The annual mileage, M , will be set at 9942 miles. This is, according to Transport Statistics Great Britain (1991), the average distance travelled for cars and taxis in 1990. The total

life expectancy of a car, T , will be set at ten years, and the real discount rate, r , at 3 percent per year. In the calculation of ϕ (the marginal benefit of fuel efficiency) we assume that the base period price, P_0^e , is equal to £2.23, which is the average price of four star leaded petrol in 1991 (see Transport Statistics Great Britain (1992)). Throughout our analysis we will assume that the expected real price of petrol P_t^e is specified as a compound value, such that, $P_t^e = P_0^e(1 + \tau)^t$, where τ is the expected rate of increase in the real price of petrol. We will assume that the real price of petrol will rise by 5% each year for the next ten years. Finally, following Atkinson and Halvorsen (1984) the formula used to calculate the lagrange multiplier of expenditure (λ) is obtained by summing equation (4) over i and solving for λ .

To calculate the elasticities of demand for attribute i with respect to the base period price of petrol, we need to substitute the estimated values from equation (16) into (6) and solve for $(\partial q_i / \partial P_0^e)$. The petrol price elasticity of demand for any one attribute is given by $(\partial q_i / \partial P_0^e) (P_0^e / q_i)$. The hypothesis that future real petrol prices can be forecast by the real base price plus a constant mark-up implies a unit elasticity of petrol price expectations. As a result, the elasticities of demand with respect to the base period price of petrol can be interpreted as the response to an expected proportional increase in petrol prices over the lifetime of a car. Table 4 shows the estimated petrol price elasticities of demand for attributes implied by the model. Since the model derives shadow prices based on a ten year horizon, the estimates in Table 4 should be interpreted as long-run elasticities. The table presents elasticities for ten cars which represent a full range of fuel efficiencies (MPG) in the sample.

Table 4

Estimated Petrol Price Elasticities

<i>Petrol Price Elasticities of Demand</i>						
Make	(Model)	MPG	Engine	Performance	Size	MPG
Audi	(Coupe 2.2)	18	-0.17	-0.18	-0.24	0.16
Ford	(Sierra Estate)	21	-0.23	-0.23	-0.30	0.20
Rover	(216 GTi)	25	-0.24	-0.25	-0.32	0.21
Renault	(Espace TXE)	27	-0.19	-0.20	-0.26	0.17
Ford	(Fiesta 1.6 S)	29	-0.31	-0.32	-0.39	0.27
Citreon	(AX GT)	30	-0.32	-0.33	-0.40	0.28
Vauxhall	(Cavalier 1.6L)	34	-0.23	-0.24	-0.31	0.20
Renault	(Clio 1.2)	37	-0.29	-0.30	-0.37	0.25
Peugeot	(205 1.1 GL)	39	-0.27	-0.28	-0.35	0.24
Renault	(5 Campus)	41	-0.35	-0.36	-0.43	0.30

The elasticities for engine capacity and performance are more or less identical suggesting an estimate of approximately -0.25. Thus, a 10% rise in the price of petrol reduces the demand for engine capacity and performance by approximately 2.5%. The results suggest that the main effect of an increase in petrol prices is to decrease the demand for larger cars. The average petrol price elasticity of demand for size is somewhat higher at roughly -0.35. A rise in petrol price induces consumers to buy smaller vehicles. This is in line with one's priors.

Perhaps the most interesting result is the effect of petrol price on fuel efficiency. As the price of petrol is increased,

the demand for fuel efficiency increases, but only slightly. Therefore, consumers are more willing to buy less fuel-intensive cars as petrol prices rise. The effect is quantitatively somewhat more modest than the effects on other attributes and the results are shown in the final column in Table 4. To calculate this, we use equation (8) together with the values of miles per gallon and the base period price of petrol. The average of the estimated elasticities is 0.23, suggesting that the fuel efficiency of new cars responds less than proportionately to changes in expected petrol prices.

In contrast, Atkinson and Halvorsen (1984) reported estimated elasticities of fuel efficiency with respect to the price of petrol in excess of unity. However, these estimates are based on a different set of car attributes; variables proxing front seat comfort and comfort of ride were included, while engine capacity is ignored. A more recent study by Greene (1990), using US data between 1978-89, presents estimates of the relative importance of economy regulations versus fuel prices in influencing new car miles per gallon. The study by Greene reports dimensionally comparable estimates, as those reported in this paper, of long-run elasticities of fuel efficiency with respect to petrol prices of around 0.21. Greene concludes that new energy and conservation standards were far more effective in influencing car manufacturers to increasing new car fuel economy than consumer responses to higher petrol prices.

In order to check the plausibility of our estimates of fuel efficiency elasticities, it is helpful to consider the following identity for total petrol consumption, D ,

$$D = (MS)/E \quad (17)$$

where S is the stock of cars. If we take logarithms of (17) and differentiate with respect to the price of petrol we get,

$$\frac{\partial \log D}{\partial \log P} = \frac{\partial \log M}{\partial \log P} + \frac{\partial \log S}{\partial \log P} - \frac{\partial \log E}{\partial \log P} \quad (18)$$

Thus, the effect of petrol price on petrol consumption is equal to the sum of elasticities of M, S and E with respect to petrol prices. Using cointegration analysis, Dargay (1993) examined the effects of income, petrol price and other variables to explain car ownership (S) and car use (distanced travelled per year (M)) and obtained long-run elasticities with respect to price of -0.63 and -0.11, respectively. These estimates can then be added to give a long-run elasticity of ownership and use of -0.74. Another approach is to examine how changes in petrol price affect the annual distance driven by cars. Dargay did this using time-series data, calculating a long-run price elasticity of -0.63. If we crudely add these elasticities to the average fuel efficiency estimate given in Table 4 we get own price elasticities of demand for petrol in the range of -0.97 to -0.86. This finding is similar to that reported in survey articles by Goodman (1992) and Dahl and Steiner (1991). More recently, Virley (1993) obtained a smaller long-run price elasticity of -0.46. However, this estimate relates to total road transport fuel consumption.

V. CONCLUSION

If consumers face high petrol costs, they could partly offset these costs by purchasing more fuel efficient cars. This paper has used the methodology of Atkinson and Halvorsen (1984) to estimate the effect of petrol price changes on fuel efficiency and other attributes using data for new cars in the UK. Variables of particular significance are engine capacity, brake horsepower, weight and size, suggesting that price and fuel efficiency can be explained by a relatively small number of attributes.

Using comparative static analysis and the estimates from hedonic regressions it was found that the main effect of an increase in petrol price is to decrease the demand for larger cars, with an elasticity of around -0.35 . In contrast with Atkinson and Halvorsen, the long-run petrol price elasticity of demand for fuel efficiency is quite low, about 0.2 . This conclusion appears consistent with the long-run estimates of own price elasticities of demand for petrol found in the literature.

Overall, the results suggest that the adjustment process within the new car market permits little substitution for more fuel efficient cars in response to petrol price changes. It, therefore, follows, that policies designed to regulate fuel economy, by imposing fuel economy standards on car manufacturers, may be more effective on new car fuel efficiency rather than increasing real petrol prices.

Footnotes:

1. An F-test was carried out on the price equation to establish if the data supported the joint exclusion of six additional characteristics, acceleration, wheelbase, piston speed, the number of models of a particular manufacturer and two zero-one dummies for imported and four-door cars. The six additional characteristics are found to be jointly insignificant at the 5% level as a set using an F-test ($F(6,188) = 1.8963$) and are thus not included in the reported specification.
2. The Box-Cox procedure was implemented using Greene's (1992) LIMDEP programme (Version 6). Scanning over the range minus 0.5 to plus 0.5, we find that the maximum likelihood estimates of λ and ω to be -0.10606 and 0.17677 respectively. However, both estimates are not significantly different from zero.

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DATA APPENDIX

LPRICE: Current manufacturer's list price of the model, excluding on-the-road charges, averaged over the year 1991 (April, Sept), from the *Autocar & Motor*.

LFUEL: Fuel efficiency measured as miles per gallon. This fuel consumption series is based on *Autocar & Motor's* standardised road test, in the *Guinness World Car Record*.

LENGINE: The engine capacity in cubic centimetres, in the *Guinness World Car Record*.

LPERFORMANCE: Power to weight ratio which is defined as maximum brake horsepower deflated by the unloaded kerb weight (measured in pounds), multiplied by 2240 (ie. expressed as brake horsepower per ton). This series is derived from the *Guinness World Car Record*.

LSIZE: The size of car defined as (length times width times height) in hundred thousand cubic inches from the *Guinness World Car Record*.



