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A possible role for discriminatory fuel duty in reducing the emissions from road transport: Some UK evidence

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ABSTRACT

In this paper it is shown that the relative demands for UK Gasoline and Diesel fuels are price responsive. Given differing emissions based externalities from these two fuel types, it is contended that discriminatory fuel duty might be a means to reduce these externalities. Results are derived from an Almost Ideal Demand System with time varying technological progress, estimated using a bootstrap procedure given non-normalities and relative small sample sizes.

JEL Classifications: Q40, R40.

Key Words: AIDS model, technology biases, time-varying parameter.

A possible role for discriminatory fuel duty in reducing the emissions from road transport: Some UK evidence[*]

David C. Broadstock[#] and Xun Chen[##]

I. Introduction

Concerns regarding diminishing supplies of global oil reserves create an imperative to consider alternative ways of motorizing the vehicle fleets of developed nations, and ideally encouraging developing nations to engender non-oil based transport infrastructures at an early stage of their development curves. Nonetheless, at present there is no clear market-ready alternatives to oil based fuels for transport.

The demand for energy for transport in the UK is dominated by two incumbents, Gasoline and Diesel. Electric based vehicle technologies have attempted to penetrate the market but with limited success.[1] Each of these incumbents is associated with quite distinct engineering technologies that result in different environmental impacts,

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[1] National statistics on electricity used for road transport show penetration at merely 0.4% of total energy for transport since 2004. There is on-going and considerable progress in the development of hybrid engine technologies, which in current forms harvest energy from the kinetic motion of the vehicle and/or under braking. Greater adoption of such vehicles in the economy may create statistical identification problems, though this is not considered further here given limited representation in the vehicle fleet.

and the need for their management is stated within a wide range of national and international planning and policy documents. Table (1) illustrates that on average gasoline is relatively more polluting than diesel for carbon dioxide, as carbon monoxide and hydro-carbons.

Table 1: Emissions from Gasoline and Diesel vehicles

Legislative vehicle class	Carbon monoxide	Hydro-carbons	Oxides of nitrogen	Particulates	Carbon dioxide
Gasoline					
Pre-Euro 1	100	100	100	2	100
Euro 1	25	9	19	1	93
Euro 2	5	3	9	1	89
Euro 3	2	1	4	1	83
Euro 4	4	1	5	1	76
Diesel					
Pre-Euro 1	6	10	37	100	91
Euro 1	3	6	34	30	88
Euro 2	2	4	40	21	83
Euro 3	1	2	31	19	76
Euro 4	1	1	19	12	72

Notes:

(i) Index: petrol car without three-way catalyst: pre 1993 = 100, for particulates, legislative standards exist only for diesel vehicles. Particulates index is diesel car: pre 1993 =100.

(ii) Data taken from the Department for Transport online statistics collection, table ENV0302 – 'Average emissions from road vehicles in urban conditions: Great Britain', available at http://www.dft.gov.uk/statistics/tables/env0302/.

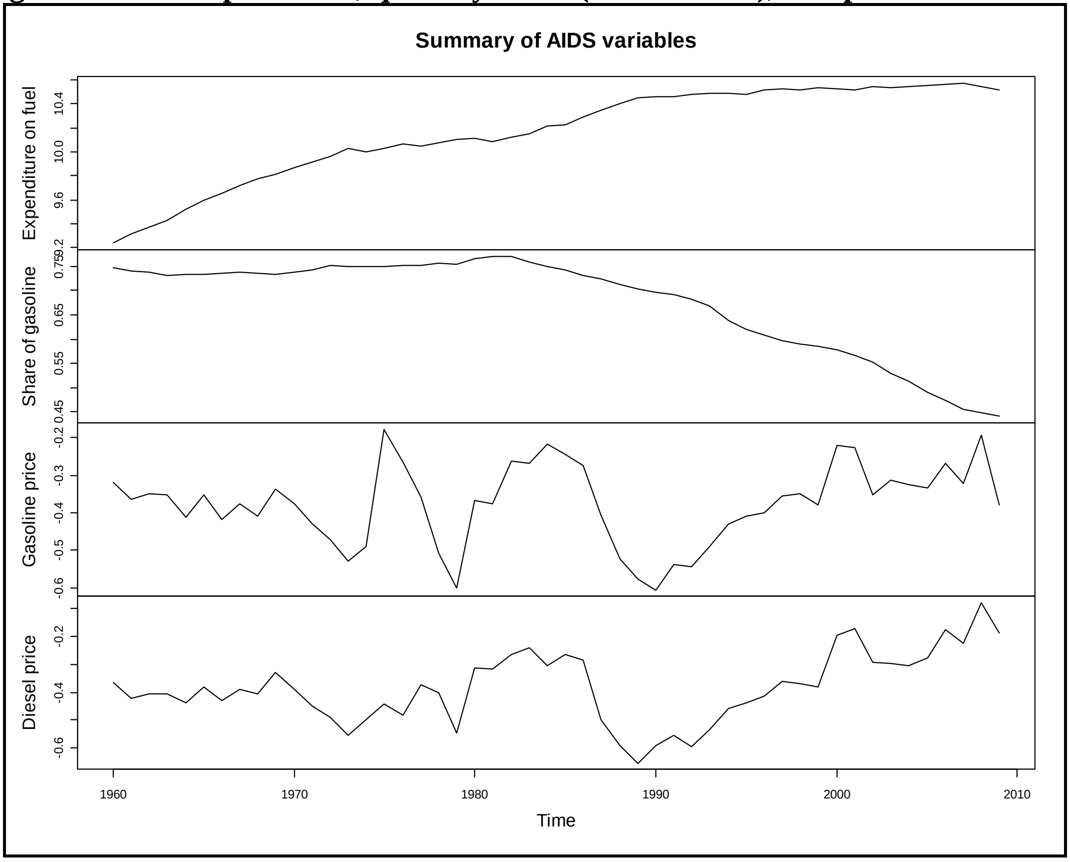
The aim of this paper is to consider what instruments are available to central planners to encourage substitution between gasoline and diesel so as to reduce the emission based externalities from road transport. After demonstrating the relative price responsiveness of the two incumbent fuels, brief discussion is offered on the nature of existing fuel duty regimes, which generally do not discriminate between Gasoline and Diesel. It is contended that discriminatory fuel duty might be a means to help manage these emissions based externalities.

The remainder of the paper is ordered as follows; the next section outlines the data. Section III discusses empirical specification, estimation methodology and derivation of substitution elasticities. Section IV summarizes the estimation and concluding remarks are offered in Section V.

II. Data

The UK annual data set covers the period 1960-2009 with energy consumption and price data taken from the Digest of UK Energy Statistics (DUKES) and the consumer price index from the UK Office of National statistics (www.statistics.gov.uk).[2] Total expenditure and expenditure shares s_g and s_d are derived and are plotted in Figure (1) along with real prices in log terms.

Fig. 1. Overall expenditure, quantity share (for Gasoline), and prices 1960-2009



[2] The price of Gasoline is a weighted-average variable over all types/grades of Gasoline. Prices are deflated to 2000 prices.

III. Methodology

Given two goods the Almost Ideal Demand System (AIDS), originally due to Deaton and Muellbauer (1980), implies the following demand share equation system;

$$
\begin{aligned}
s_{g,t} &= \tau_{g,t} + \beta_{gg} \ln p_g + \beta_{gd} \ln p_d + \delta_g \ln\left(\frac{x}{a(P)}\right) + \zeta_{g,t} \\
s_{d,t} &= \tau_{d,t} + \beta_{dg} \ln p_g + \beta_{dd} \ln p_d + \delta_d \ln\left(\frac{x}{a(P)}\right) + \zeta_{d,t}
\end{aligned}
\qquad (1)
$$

Where $s_{g,t}$ and $s_{d,t}$ are the demand shares for Gasoline and Diesel respectively at time t, τ represents a measure of technological progress whose measurement is discussed in more detail below. The β's and δ's are parameters to be estimated while $\ln p$ denotes the log of prices. $(x = q_g p_g + q_d p_d)$ is the total expenditure on fuel and $a(P)$ is the Stone price index $(a(P) = s_g^B p_g + s_d^B p_d)$.[3]

Standard regulatory constraints are imposed such that $\beta_{ij} = \beta_{ji}$ for *j=(g,d)*, $\sum \beta_{ij} = 0$, $\sum \delta_i = 0$ and $\sum \tau_{i,t} = 1$ to ensure a well behaved consumption function. Equation (1) is estimated by omitting Diesel from the system and dividing the price of Gasoline by the price of Diesel, thus leading to a single share equation to be estimated:

$$
s_{g,t} = \tau_{g,t} + \beta_{gg}(\ln p_g - \ln p_d) + \delta_g \ln\left(\frac{x}{a(P)}\right) + \zeta_{g,t} \qquad (2)
$$

The remaining system parameters are then derived using standard cross equation constraints

[3] Following Deaton and Muellbauer (1980) and Buse (1994), collinearity in prices justifies the use of the Stone price index.

Measuring technology

Recently, parameter constancy in AIDs models has been relaxed in favour of more general time varying specifications, see for example Moosa and Baxter (2002) and Li *et al.* (2006). The approach of Harvey (1989) is used to allow $g(\tau_{g,t})$ to be a time varying function modelled using a Kalman filter/smoother and a maximum likelihood estimator. Specifically, technology is modelled as a local linear trend:

$$\begin{aligned} \tau_{i,t} &= \tau_{i,t-1} + \mu_{i,t} + \xi_t^{(1)} \\ \mu_{i,t} &= \mu_{i,t-1} + \xi_t^{(2)} \end{aligned} \qquad \text{(3a-3b)}$$

Where $\xi_t \sim NID\left(0, \sigma_\xi^2\right)$ and $\xi_t^{(i)} \sim NID\left(0, \sigma_{\xi^{(i)}}^2\right), i = 1,2$. Equations (3a) and (3b) represent the level and slope of the trend respectively.

Given estimates for the terms in Equation (2), and the remaining parameters derived using the regulatory constraints, following for example De Mello et al (2002) *inter alia*, the income and substitution elasticities are derived as:[4]

Expenditure elasticity

$$\varepsilon_g = \frac{1}{s_g}\frac{\partial s_g}{\partial \ln(x)} + 1 = \frac{\delta_g}{s_g} + 1$$

Uncompensated own-price elasticity

$$\varepsilon_{gg} = \frac{1}{s_g}\frac{\partial s_g}{\partial \ln(p_g)} - 1 = \frac{\beta_{gg}}{s_g} - \delta_g \frac{s_g^B}{s_g} - 1$$

[4] Noting a correction to the compensated cross-price elasticity formula reported by De Mello et al (2002).

Uncompensated cross-price elasticity

$$\varepsilon_{gd} = \frac{1}{s_g}\frac{\partial s_g}{\partial \ln(p_d)} - 1 = \frac{\beta_{gd}}{s_g} - \delta_g \frac{s_d^B}{s_g} - 1$$

Compensated own-price elasticity

$$\varepsilon_{gg}^* = \varepsilon_{gg} + s_g^B \varepsilon_g = \frac{\beta_{gg}}{s_g} + s_g^B - 1$$

Compensated cross-price elasticity

$$\varepsilon_{gd}^* = \varepsilon_{gd} + s_g^B \varepsilon_g = \frac{\beta_{gg}}{s_g} + s_d^B$$

The following section presents and discusses the results from estimating equations (2) with (3a-3b).

IV. Results

Three aspects of the results will be discussed: Firstly, the significance of the estimated parameters will be considered: Secondly, the derived substitution elasticities are discussed; Thirdly, the bias in technological progress is given.

Parameter significance

Given the demand system has only two goods, it is not possible to directly estimate all parameters of the system: from the gasoline share equation β_{gd} does not get estimated, likewise from the diesel share equation β_{dg} does not get estimated. As a solution to evaluate the general robustness of the conclusions and also due to relatively limited sample sizes, the significance of the estimated parameters is approximated using the bootstrap process outlined by Stoffer and Wall (2004). The estimation results are reported in Table (2).

Table 2: Estimation results of the ST-AIDS model

	Coefficient	Std. error
Estimated parameters (asymptotic S.E.'s)		
β_{gg}	-0.1818	0.0105
δ_g	-0.0239	0.0709
Derived parameters (bootstrap S.E.'s)		
β_{gd}	0.1818	0.0202
β_{dg}	0.1818	0.0202
β_{dd}	-0.1818	0.0202
δ_d	0.0239	0.2040
Diagnostics		
Log-likelihood	220.6665	
Box-Ljung (lag-one)	0.0135	
Jarque-Bera	2.131	

Notes:

(i) Diagnostics checks are based on the standard parametric results;

(ii) Given the model symmetry, the absolute values of bootstrap standard errors for β_{gg} and δ_g are equivalent to those for β_{dd} and δ_d respectively;

(iii) Symmetry in the bootstrap standard errors is a by-product of the simplicity of the two good share system;

(iv) Bootstrap estimates based on 500 replications

The diagnostics tests reveal residual normality and no serial-correlation in the standard asymptotic estimates. The standard errors, both asymptotic and bootstrap, suggest that prices are significant while income is not. The empirical bootstrap distributions are plotted in Figure (2). The price coefficients are fairly normally distributed, while the income effects are heavily skewed to the left, thus further validating the use of the non-Gaussian inferential procedure.

Substitution elasticities

The derived substitution elasticities are summarized in Table (3), while the main elasticities of interest, the compensated cross price elasticites, are plotted in Figure (3). The elasticity values are broadly as would be expected, with own price elasticities all being negative and cross price elasticites all being positive, confirming that the fuels are substitutes. On average, the own-price and cross-price elasticities for Gasoline are much lower than for Diesel.

Fig. 2. Empirical bootstrap distributions from 500 bootstrap replications.

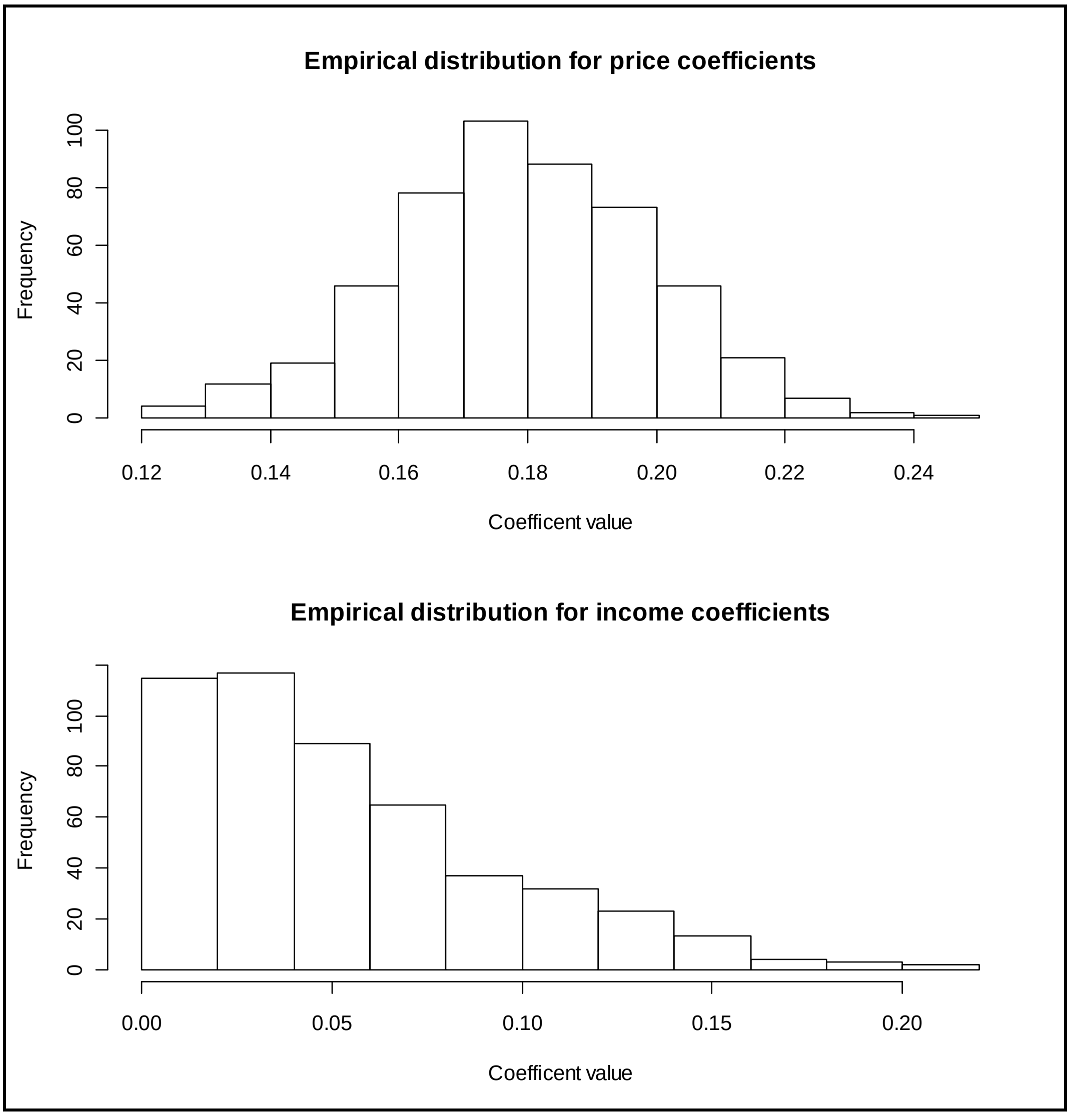


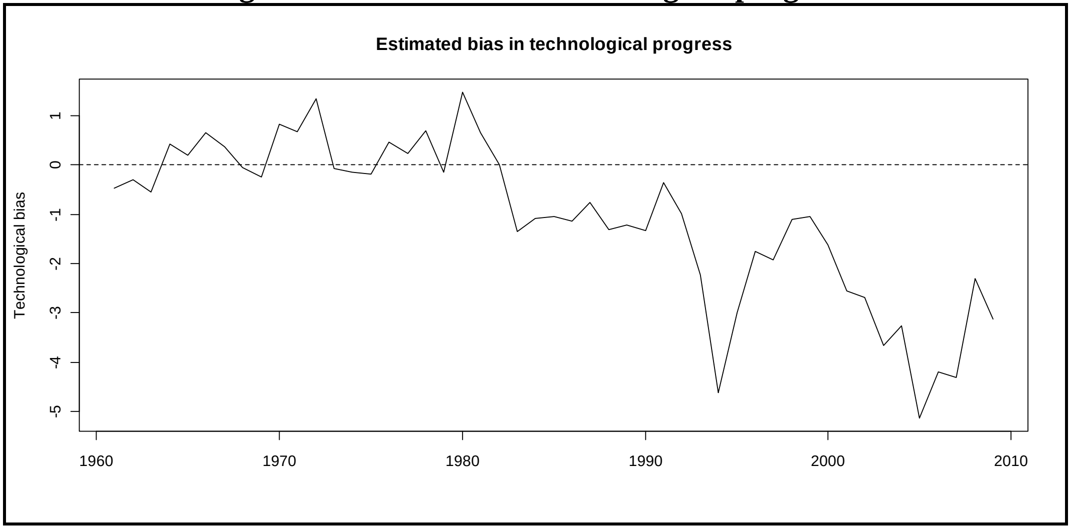
Table 3: Expenditure, Compensated and uncompensated substitution elasticities

	Expenditure		Price (uncompensated)				Price (compensated)			
	ε_g	ε_d	ε_{gg}	ε_{dd}	ε_{gd}	ε_{dg}	ε^*_{gg}	ε^*_{dd}	ε^*_{gd}	ε^*_{dg}
1960	0.968	1.097	−1.223	−1.776	0.255	0.679	−0.669	−1.306	0.808	1.048
2009	0.939	1.039	−1.426	−1.316	0.487	0.277	−0.889	−0.871	1.024	0.721
Average	0.963	1.080	−1.258	−1.641	0.294	0.561	−0.706	−1.179	0.845	1.024
(std. dev.)	(0.008)	(0.021)	(0.054)	(0.170)	(0.062)	(0.149)	(0.058)	(0.161)	(0.057)	(0.158)

Notes:

(i) if $\sigma > 0$ then substitutes, if $\sigma < 0$ then complements.

Fig. 3. Estimated bias in technological progress.



The impact of technological progress

Following Harvey and Marshall (1991) the bias in technological progress can be approximated as:

$$B_i = \frac{100[\tilde{\tau}_{i,t|T} - \tilde{\tau}_{i,t-1|T}]}{s_i}$$

Where $\tilde{\tau}_{i,t|T}$ denotes the smoothed estimates of the time varying technology. This measure is more informative than simply plotting the estimated technology trends, as it reflects the relative position of existing demands. Figure (3) plots the calculated bias in technological progress. This graph shows that prior to 1980 the effects of technology were fairly evenly spread between Gasoline and Diesel, however since the early 1980's the bias in technology has been favouring Diesel fuel.

V. Discussion and Conclusions.

With a view to considering the policy options available to help mitigate the emissions based externalities of road transport, this paper has demonstrated that the relative shares of the two incumbent fuels (Gasoline and Diesel) in UK road transport are price elastic. In the introduction it was also shown that the emissions from diesel were generally lower. Though tax rates were not explicitly featured in the model, it is clear that price based instruments can significantly influence the relative shares of demand, and hence emissions.

At present the UK fuel duty policy does not generally discriminate between gasoline and diesel, with the exception of some biodiesels – this will offer some benefits in terms of overall emissions reduction as for instance Yohe (1979) pointed out, but fails to reflect the unique characteristics of the two fuels. In light of the evidence offered by the empirical model, there is justification to reconsider homogeneity in the fuel duty, and instead allow for a discriminatory fuel duty regime that offers lower relative duty rates for diesel than for gasoline. The bias of the technology clearly favours Diesel fuels in recent years, and in line with the above discussion, suggests that policy instruments to support investment in diesel technology may also help to encourage inter-fuel substitution.

Bibliography

Buse. A., (1994), Evaluating the linearized almost ideal demand system, *Am. J. of Agric. Econ.*, **74**(4), 781-793.

De Mello. M., Pack. A and Sinclair. M.T., (2002), A system of equations model of UK tourism demand in neighbouring countries, *Appl. Econ.*, **34**, 509-521.

Deaton. A, and Muellbauer. J., (1980), An Almost Ideal Demand System, *Am. Econ. Rev.*, **70**(3), 312-326.

Harvey. A.C., and Marshall. P., (1991), Inter-fuel substitution, technical change and the demand for energy in the UK economy, *Appl. Econ.*, **23**, 1077-1086.

Moosa. I.A. and Baxter. J.L., (2002), Modelling the trend and seasonals within an AIDS model of the demand for alcoholic beverages in the United Kingdom, *J. of Appl. Econom.*, **17**, 95-106.

Stoffer, D.S. and Wall, K.D., (2004), "Resampling in state space models", In *State Space and Unobserved Component Models Theory and Applications*, Chapter 9. 227-258. Andrew Harvey, Siem Jan Koopman and Neil Shephard, Eds. Cambridge University Press.

Yohe, G.W., (1979), Taxing consumption to finance reduced emissions: An alternative pollution control, *Econ. Lett.*,**2**(1), 1-4.

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