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Estimating demand for new car fuel economy in the UK 1970-2004 using a two-stage error correction model

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David Bonilla and Tim Foxon

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David Bonilla[a] and Tim Foxon[b]

[a] EU Marie Curie Research Fellow, Cambridge Centre for Climate Change Mitigation Research (4CMR), Dept. of Land Economy, University of Cambridge.

[b] UK Energy Research Centre Research Fellow, Cambridge Centre for Climate Change Mitigation Research (4CMR), Dept. of Land Economy, University of Cambridge

Abstract

Over the past 30 years, governments have sought to stimulate improvements in new car fuel economy to contribute to air quality, energy security and climate change goals. We analyse the demand for new car fuel economy in the UK using a two-stage econometric model to investigate the drivers of this demand in the short and long run over the period 1970-2004.We find that higher incomes and long run price changes are the main drivers to achieve improvements in fuel economy particularly for gasoline cars; and that new car fuel economy changes were scarcely induced by the Voluntary Agreement on CO_2 emissions reductions adopted in the 1990s. We find that the demand for fuel economy is price inelastic for both fuels, in agreement with other studies. Our calculated long run income elasticity (gasoline with -0.31 and diesel fuels with -0.20) values are above the range of international studies for gasoline but within the range for diesel.

JEL Classification: Q2, Q4, R4
Keywords: fuel economy policy and standards; energy policy; energy demand; resource conservation; transport policy.

Address for correspondence
Dr David Bonilla,
EU Marie Curie Research Fellow,
Cambridge Centre for Climate Change Mitigation Research (4CMR),
Dept. of Land Economy,
University of Cambridge,
19 Silver Street,
Cambridge CB3 9EP, UK.
Tel: +44 1223 764874.
Fax: +44 1223 337130
E-mail: db408@cam.ac.uk

1. Introduction

In this paper, we estimate the price and income elasticity of demand for fuel economy (litres per 100 km) of new U.K. cars in 1970-2004 using a two-stage econometric model following Engle and Granger (1987) to investigate the drivers of this demand in the short and long run over the period 1970-2004.[1] We estimate how fuel economy of new cars is affected by (1) fuel price changes; (2) increases in personal incomes; and (3) the introduction of the EU Voluntary Agreements (standard) with car manufacturers for reductions in CO_2 emissions per kilometer. This paper analyses time-series data for the UK to disentangle these different effects on fuel economy, using separate data series for gasoline and diesel vehicles. This should inform debate on the combination of measures needed to improve fuel economy and reduce CO_2 emissions from UK road transport.

In the U.K., new car fuel economy and on-road fuel economy (of entire car fleet) have steadily improved since the late 1970's but the overall energy use of the sector, and its emissions of greenhouse gas, continue to grow (Table 1). New car fuel economy determines, at least partly, on-road fuel economy improvements and future growth in road transport energy demand and CO_2 emissions. However, test fuel economy of new cars *diverges* from on-road fuel economy, and so there is uncertainty in how effective fuel economy standards are in mitigating growth in energy demand of the sector. How quickly overall fuel economy improves also depends on vehicle sales and the rate of turnover of the vehicle stock, which is determined by macroeconomic conditions (Greenspan and Cohen, 1996).

So, despite improvements in new car fuel economy in the UK since 1970 and the adoption of the EU Voluntary Agreements in 1998, energy demand and CO_2 emissions from private cars have continued to rise up to 2004. However, the UK government expects that recent policy measures , including graduated fuel duty and Voluntary Agreements, will reduce fuel use by road vehicles by 6% by 2010 (Secretary of State for the Environment, 2006). [2] Improving vehicle fuel economy can also help to reduce seven types of air

[1] Note that we use the European measure of fuel economy in litres per 100 kilometres. Hence, a reduction in the numerical value represents an improvement in fuel economy (fewer litres per 100 km). This is the inverse of the U.S. measure of fuel economy in miles per gallon.

[2] Energy use in road transport in the last 30 years is explained mainly by two effects: First, UK drivers are now driving longer distances per journey on average (DfT, 2006), and

pollutants (carbon monoxide (CO), carbon dioxide (CO_2), lead (Pb), black smoke (BS), sulphur dioxide (SO_2), hydrocarbons (HC), and nitrogen oxides (NO_x)) are of particular concern for health and environmental reasons. (UK Department of Health, 1998).

Table 1: Trends in Private Car Transport in the UK in 1975-2004

	1975	1980	1990	1995	2004	% change pa. 1975-2004	
Energy consumption (million tonnes oil equivalent)	15	17	23	22	23	+1.8%	
Emissions CO_2 (MtC)	13	15	19	19	20	+1.44%	
Vehicle km (billions per year)	182	227	328	351	398	+2.3%	
Vehicle stock (000's)	12,526	14,660	19,742	20,505	25,754	+2.9%	
Fuel economy new gasoline cars (l/100km)	10.5	9.3	8.2	8.1	7.5	-1.2%	
Source: DfT, 2006; Transport Statistics Great Britain, 2006. DfT website and DTI, 2006.							

The model and results presented in this paper are first step to build a model of transport within the Cambridge Multi Dynamic Model of the UK Economy following Johnstone (1995),which will enable a detailed examination of trends and policies that affect new car fuel economy, energy consumption and key technological characteristics that determine fuel economy and pollution emission rates. [3]

second, the UK vehicle stock has grown strongly (Table 1). The latter has increased more rapidly than kilometres driven per vehicle, hence contributing more to growth in energy use.

[3] N. Johnstone, Modelling Passenger Demand, Energy Consumption and Pollution, Emissions in the Transport Sector, *Department of Applied Economics, University of Cambridge, Working Papers Amalgamated Series* (1995). For a model description of the Cambridge Multisectoral Dynamic Model (MDM) of the United Kingdom economy see Barker and Peterson (1987).

The paper is structured as follows: Section 2 contains a discussion on the environmental effects of road transport, Section 3 a historical discussion on new car fuel economy regulation; Section 4 discusses a literature review; Section 5 an overview of the entire model; Sections 5 and 6 describe the two stage cointegration equation of fuel economy and econometric results in the analysis of automotive fuel economy. Section 7 concludes.

2. Historical data on UK fuel economy and fuel demand

How new car fuel economy (litres/100 km) for gasoline cars (TSGB, 2006) and gasoline price (UK pence/liter) (DTI, 2006) have varied for the UK over the period 1970-2004 is shown in Figure 1.[4] New car fuel economy has responded negatively (less gasoline consumed per kilometre) to higher gasoline prices during the 1980's (Figure 1; Appendix). The second round of high gasoline price increases (1999-2000) did not lead to equally larger adjustments in fuel economy as it did in the first two rounds (1975 and 1984).

[4] Official fuel economy data excludes four wheel drive vehicles, but sales of four wheel drives cars have historically increased, and so true fuel economy level may be higher (more liters per km) than estimated.

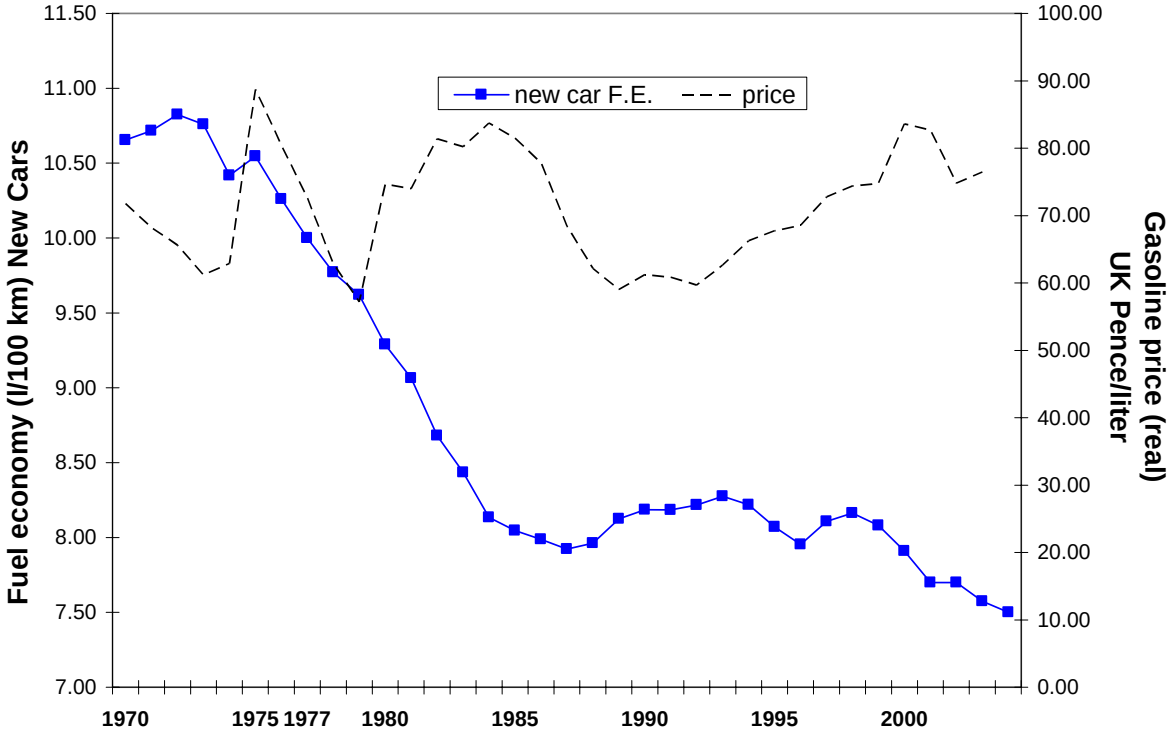

Figure 1. New car Fuel Economy (Gasoline) and price (TSGB; DTI,)

In the U.K., new car fuel economy and on-road fuel economy (of entire car fleet) have steadily improved since the late 1970's despite long periods of low real gasoline prices, excluding brief periods of price peaks in the early 1970's, 1980's and in early 2000 (Table 1). See Appendix for trends in on-road fuel economy. Fuel economy for new gasoline vehicles first reacted strongly to gasoline price increases in the 1979-87 (Figure 1).[5] Because of the absence of the fuel economy standards coupled with low gasoline prices at that time, fuel economy improvements are partially reversed in 1987-93. The fuel economy level seen in 1993 was the same level as that of 1983. After 1993, improvements in fuel economy appear and are then again reversed for a brief period in the late 1990s but then reappear in the last years. These events are a result of policy developments, including the introduction of vehicle excise duty based on CO_2 emissions and of Voluntary Agreements on CO_2 emissions reductions, discussed below, as well as of gasoline price changes (partly driven by the fuel duty escalator policy) and income

[5] In this paper we do not explicitly account for technology diffusion. It is likely that imports of Japanese vehicles, which are more fuel efficient, in the early 80's significantly improved (fleet wide) fuel economy of UK roads.

effects. See Appendix for trends in fuel economy of diesel vehicles and for cost per kilometer trends.

Fuel demand for passenger cars (gasoline and diesel) accounts for 40% of total UK oil consumption, as shown in Figure 2. This demand has grown significantly in the 1980's and 1990's but has recently reached a plateau, albeit at a record historical level. The demand for fuel, and hence CO_2 emissions, from the domestic transport sector is expected to level out and fall by 2020, because of saturation effects and further policy measures (DTI UEP, 2006).

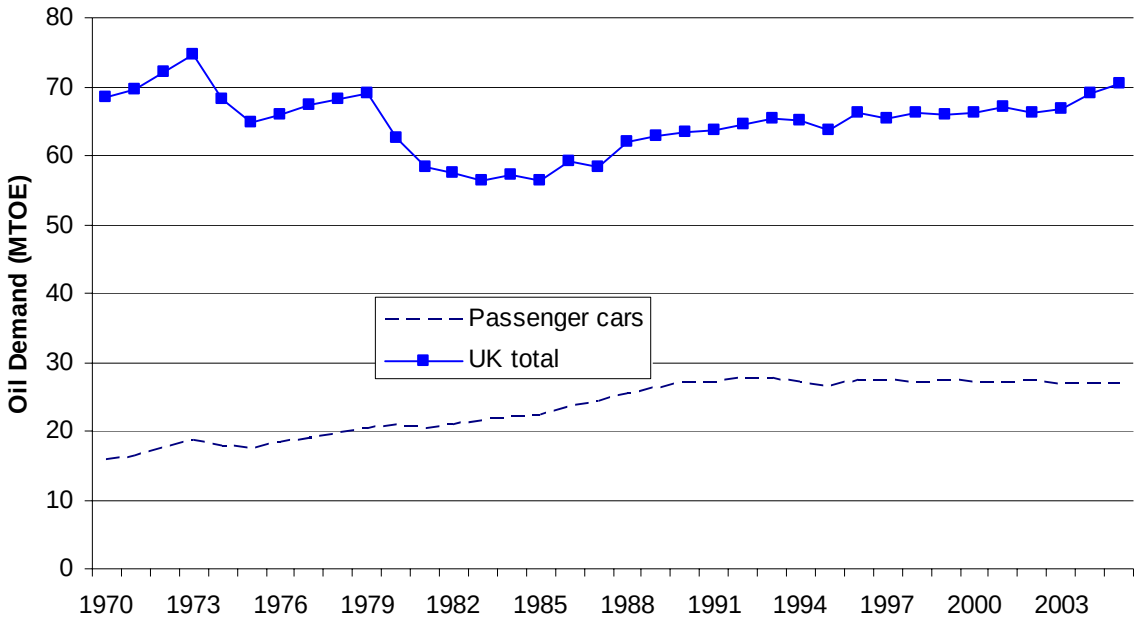

Figure 2. Oil Consumption of cars and total UK (DTI, 2006)

The largest reduction is expected to come from road fuel demand as growth in demand for transport services moderates, fuel economy in transport continues to improve and lower-carbon fuels, especially biofuels, increase their market share.

Fuel demand per kilometre driven, of private vehicles, is both price inelastic and income inelastic, as shown below, implying that consumption will fall less than proportionately to changes in fuel prices.

3. The History of Vehicle Fuel Economy Regulation 1970-2005 in the U.K.

Following the oil price shocks of the mid-1970s, a voluntary target of a 10% improvement in the UK national model average fuel consumption between October 1978 and October 1985 was agreed (Sorrell, 1992). In December 1983, the Society of Motor Manufacturers and Traders (SMMT) announced that this target had been met two years early. This was independently verified by Rice and Parkin (1984), who found a 13.2% improvement over the 5 year period, largely (10.5%) due to technical improvements in fuel economy with smaller contributions from the purchase of smaller vehicles (1.0%) and reduction in average engine size (1.7%). Sorrell (1992), however, argues that this improvement should be attributed largely to a lagged response to the oil price shocks, rather than to the voluntary agreement of the early 1980's. With declining oil prices and robust deregulatory government policy of the 1980's, fuel economy subsequently languished as a political issue in the UK until concerns about CO_2 emissions led to renewed political interest in the 1990s.

In 1993, a fuel duty escalator was introduced, i.e. above inflation annual increases in fuel duty, to stimulate behavioural improvements in fuel economy and reductions in fuel demand for environmental reasons. This contributed to the rise in fuel prices in the second half of the 1990s, until the escalator was discontinued in 1999, due to political unacceptability of high fuel prices, which led to mass protests by freight hauliers and farmers in 2000.

The main policy measure to reduce vehicle CO_2 emissions is now the UK's participation in the European Union Voluntary Agreements to stimulate technical improvements in vehicle efficiency. In the late 1990s, the European Commission secured voluntary agreements with European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturers to reduce new car CO_2 emissions to 140 gCO_2/km between 1998 and 2008/09. This represents a cut of 25% on 1995 levels. The 140 gCO_2/km target is a sales-weighted average to be met at a European level by each motor manufacturing association. The UK, which started from a level above the European average position (mainly due to the lower level of diesel penetration in the UK) is likely to be one of the countries with a higher average emissions per kilometer. The UK Government's central forecast for new cars in the UK is 162gCO_2/km in 2008. In 2006, the DfT launched an 'initial informal consultation' on possible EU-level policy options to succeed the current Voluntary Agreements (DfT, 2006), and the EU Transport

Commissioner proposed a mandatory European target of 130 gCO_2/km by 2010. The possibility of including the road transport in the EU emissions trading system is also being considered.

Figure 3 shows CO_2 emissions per kilometre for new cars (weighted average of gasoline and diesel) and for the car fleet level.

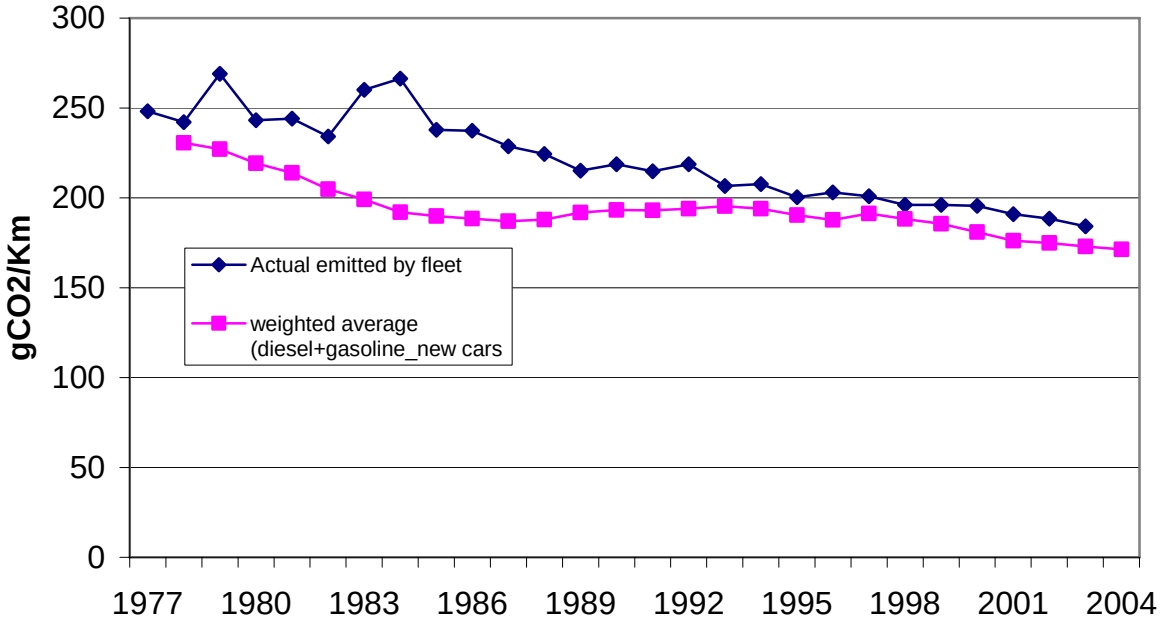

Figure 3. CO2 emissions vehicle Fleet wide and new vehicle

Data shows that the trend in actual emissions (grams of CO_2/km driven) first widens from that of new car emissions between 1978-1992 but, after 1992, the gap in emissions narrows. The slope in emissions of new cars (and of vehicle fleet) shifts downwards after accelerated introduction of diesel cars during the early part in the 1990's decade.[6] The rate of decline in fuel economy (in terms of CO_2/km) of new UK vehicles is so far insufficient to achieve the 2008 target of 140 g CO_2/km as enshrined in the EU Agreeement.[7] As of 2004, new car fuel

[6] Data for kilometers driven and for fuel efficiency of new cars (DfT, 2006, Table 2.8). Data on vehicle stock from DfT (2006).

[7] Other main policy measures to reduce the ratio of CO_2/km driven include the Fuel Duty Escalator (to 1999), the Graduated Vehicle Excise Duty (now based on CO_2 emissions from £0 for Band A to £220/yr for Band G), and the Company Car Tax (now also based on CO_2 emissions). In addition, a Renewables Transport Fuel Obligation will be introduced from 2008/09 for an annually increasing proportion of fuels to be renewable (bio) fuels.

economy stands at 171.3 g CO_2/km, which would imply an unrealistic annual reduction of 7.8 g CO_2/km to reach the 2008 target.

4. Literature review on fuel economy and gasoline demand

Table 2 summarises major studies on fuel economy of new cars, which use a range of econometric methods. This list of studies is not exhaustive and we only show the most important studies. The listed estimates of elasticities are statistically significant. Positively and negatively signed price elasticities vary according to fuel economy definitions. The listed studies use, as the dependent variable, new car fuel economy in miles per gallon (mpg) and tend to focus on gasoline. A study resembling ours is that of Santini and Vyas (1988) who regress the change in fuel economy (miles per gallon) for new cars against the change in regulatory standard of CAFE for the U.S.

Three studies (Small-Van Dender (2006); Zachariadis and Clerides (2006); Johansson-Schipper, 1997) focusing on the OECD region, report widely different elasticities ranging from -0.01 to -0.6. An important study by Baltagi and Griffin (1983), using various econometric estimators, find wide price elasticity estimates ranging from -0.08 to -0.17 (lag distribution model) and -0.64 to -0.92 (various estimators). Baltagi and Griffin also find widely varying income elasticities: 0.61 to 0.84.

All of the studies cited in Table 2 give wide variations of price elasticity of fuel economy because of differences in functional form, period of estimation and estimation technique. Hardly any study, however, on new car fuel economy, has used the error correction (ECM) framework where covering an entire vehicle market partitioned on the basis of fuel type. Second, studies give inadequate attention to fuel economy and to models of fuel economy explicitly (Graham and Glaister, 2002). Third, unlike Witt (1997) and Greene (1990) who examine selected car makes, our model includes data on aggregate fuel economy. To our knowledge, most studies have not used the cointegration technique to estimate the fuel economy trends, neither estimated separate behaviour of gasoline and of diesel fuel economy; nor focused on short and long run effects on fuel economy of new cars.

However, the cointegration methods, with ECM or without it, have been applied by Bentzen (1994); Samimi (1995); Elton and Al-Mutairi; (1995) and Ramanathan (1999) for the purpose of estimating gasoline demand. The Ramanathan and Bentzen

studies use the ECM within a cointegration approach. The approach has also been applied in a vector ECM framework for the analysis of energy consumption (Masih, 1997).

Table 2: Price Elasticities of Fuel Economy (gasoline)

Variable	Dependent variable	Method[8]	Period of estimation And country	Price elasticity	Income elasticity
Small-Van Dender (2006)	gal./mile	(3SLS, OLS)	1966-97 (U.S.); obs: 1734	-0.2 to : -0.35	0.013
Zachariades-Clerides (2006)	l/100km	(PANEL)	1978-2004 (World, U.S.; EU; Japan, etc)	-0.20 to -0.27	-0.01 (OECD); -0.07 (EU); -0.03 (North Am.)
Johansson-Schipper (1997)a	l/km	(PANEL; GLS; OLS)	1973-1992 (OECD)	-0.05 to -0.38	-0.04 to -0.6
Puller and Greening (1999)	mpg	(PANEL)	1980-90 (U.S.); (household)	0.02 to 0.13	0.002 to 0.003
Witt (1997)	mpg	(ML)	U.K.	0.17 to 0.30	na.
Espey (1996)a	mpg	(ML)	1975-1990 U.S. U.K. Japan, Germany, Norway, Sweden, Denmark	0.09 to 0.26	-0.0005
Dahl (1995)	mpg		Survey of U.S. and countries	0.05 to -0.36	-0.06 to -0.21
Gately (1990)	mpg	(TS)	1966-88 (U.S.)	0.01 to 0.17	na.
Greene (1990)	mpg	(CS)	1978-89 (U.S.)	0.08 to 0.21	na.
Atkinson-Halvorsen (1984)	mpg	(CS)	1978 (U.S.)	1.25 to 1.82	na.
Sweeney (1979)	mpg	(TS)	1957-74 (U.S.)	0.06 to 0.21	na.

[8] Study type: CS=cross section; TS=time series; GLS=generalized least squares; ml=maximum likelihood; 3SLS= Three Stage Least Squares.

a: average fleet fuel economy is the unit of dependent variable. Listed price elasticities are long run ones.

5. Overview of the two stage error correction model

In the main model, fuel economy (of new cars) is estimated over the historical period on the basis of cointegrated equations to establish if there is a long run relationship among macroeconomic variables and fuel economy. The ECM method, as reported in Alogoskoufis and Smith (1991), involves reparameterisation of dynamic linear regression models in terms of differences and levels.

Fuel economy equations, are specified in technological terms, but are integrated with behavioural (consumer demand for fuel economy, personal income) and institutional responses (voluntary emission reductions). Fuel economy is linked to economic functions described below.

5.1 Estimating fuel economy of new cars in the UK

In this Section we define our econometric model of new car fuel economy. The model is estimated using time-series data of 1970-2003 to capture the price and income elasticities of fuel economy for UK cars (see Appendix for data sources). Our models capture consumer preferences via purchases of higher or lower new car fuel economy.

We use the Engel and Granger (1987) error-correction mechanism (ECM) model. The two stage procedure that we use here is suggested by Hall (1986) and Engle and Granger (1987). The procedure involves a long run and a short run treatment of fuel economy. In this formulation, the residual of the long run equation, for fuel economy, in (1), gives the ECM term. The ECM term is then used in the short run equation (2) as an explanatory variable, with its coefficient representing the speed of adjustment towards the long-run trends. The long run equation is given in levels and the short run one is defined in first differences. Equation (1) and (2) are applied to new car fuel economy of diesel engines and of gasoline engines.

The choice of explanatory variables of our model follows other studies.[9] The long run fuel economy for gasoline and diesel new vehicles is estimated using an equation of the following form:

$$\ln FE_{i,t} = \beta_{0,i} + \beta_{1,i} \ln RPDI_t + \beta_{2,i} \ln PFU_{i\,t-1} + \beta_{3,i} \ln STA_{i,t} + ECM_t \quad (1)$$

$$\begin{aligned} \Delta \ln FE_{i,\,t} = {} & b_1 + b_2\, \Delta \ln \left(PFU_{i,\,t} \right) + b_3\, \Delta \ln \left(FE_{i,\,t-1} \right) + b_4 \Delta \ln \left(RPDI_t \right) \\ & - \phi \left(\ln FE_{i,t-1} - \beta_0 - \beta_1 \ln RPDI_{t-1} - \beta_2 \ln PFU_{i,t-2} - \beta_3\, STA_{t-1} \right) \\ & + \varepsilon_{\,t} \end{aligned} \quad (2)$$

Where,

$$\Delta \ln(FE_{i,\,t}) = \ln FE_{i,\,t} - \ln FE_{\,i,\,t-1} \quad (3)$$

And the rest of X_k variables are transformed similarly,

$$\Delta \ln(X_{k\,t}) = \ln X_{k\,t} - \ln X_{k\,t-1} \quad (4)$$

Where,

Δ	= first differences of the natural logs;
FE	= fuel economy of new cohort of fuel *i* in year *t*. (l/100km)[10];
RPDI	= real personal disposable income (000's £);
$PFU_{i\,t}$	= price of fuel *i* in year *t* (UKp./liter);
STA	= fuel economy standard (dummy variable);
EC	= error correction term;
i	= fuel type (gasoline or diesel);
ln	= natural logarithms.

And coefficients,

ϕ	= coefficient of the ECM or speed of adjustment of new car fuel economy;
$b_{3,i}$	= desired fuel economy from period t to period t-1;
b_i	= coefficients to estimate;

[9] Sterner and Dahl (1992); Small-van Dender (2006) and Zachariadis and Clerides (2006).

[10] Fuel economy data of new cars is registration weighted. The figure is obtained by grouping the models in the official new car fuel consumption list into 100cc engine size bands (DfT, 2006, pp.48)

ε_t = residual error;

$\beta_{1,i}$ = coefficients to estimate;

φ_{t-1} = coefficient for error correction term with one year lag.

The dummy variable is set up as an interaction dummy (1970-95=0, 1995-2003= fuel economy value) variable for gasoline fuels; and for diesel fuel as: Dummy=1 for 1995-99, otherwise 0. The dummy should capture if the Voluntary Agreement, coming into force in 1995 to meet 140g. CO_2/km by 2008, reduced the ratio of litres per km.

Hence, long run fuel economy, with all variables in logs, is estimated as a function of real personal disposable income, gasoline price and a dummy variable, as the explanatory variables.

The time (observation) specific dummy should also capture the effects on new car fuel economy such as: (a) the ownership tax imposed annually since 1997 (based on six bands according to carbon emissions); and (b) the EU Voluntary Agreement on CO_2 emissions of cars. In (1) it is assumed that car manufacturers responded to the announcement of the agreement in 1995, rather than its implementation in 1997/98 (cf. Agnolucci et al. 2004).

The fuel economy variable is transformed by taking first differences in annual data which allows the model to capture the short run response of fuel economy. In equation (2) changes in fuel economy are spurred by changes in gasoline price, real personal disposable income and past fuel economy. Hence this model is dynamic. Equation (2) uses the residuals from the long-run equation, ECM_{t-1}, which serves to force the short-run variations back to the long-term trend.; this equation relates changes in fuel economy as a function of explanatory variables and a disequilibrium error captured by the ECM term. Values for ECM are estimated in the long run equation (1). Equation (2) shows the estimated ECM coefficient, ϕ, representing the speed of adjustment towards the long run trends. Equation 2 can also be seen as a model using growth rates in the right hand and left hand variables following transformation of the variables.

5.2 Stationarity and Cointegration Tests

To establish if cointegration applies to models (1) and (2) tests are peformed for unit roots and for cointegration. Unit roots (using Dickey and Fuller criterion; Dickey and Fuller,

1981) tests are performed for each series in (1) and (2) in a univariate basis for both fuels. Dickey and Fuller tests do not show stationarity for all variables in levels (hence unit roots are present). After first differencing, the same variables in (1), tests only show stationarity, I (1), for the series of personal income (with and without a lag) while tests are indeterminate for the other variables. In the multivariate case, the Engle Granger ADF test is also performed on the residuals of equation (2). The Engle and Granger, and the ADF test, show stationarity (I (0) in the residuals of (2) with a significant t-statistic of -4.75 (at 8.1% probability). Such test is performed on a model (with first differences and in natural logs) containing: fuel economy, personal disposable income, past fuel price and past fuel economy and the ECM parameter, as in (2).[11]

Using the analogous variables the Engle Granger ADF test for diesel gives t-statistic of 3.93 (significant at 15% probability level) without lags and a t-statistic of 2.64 (one lag). These tests are indeterminate to ascertain stationarity in Eq. (2) for diesel fuel. For single series tests are also weak for stationarity.

The β's of (1) and (2) represent the elasticities of fuel economy with respect to the explanatory variables.[12] The use of these equations allows for distinctions to be made between short-run and long-run changes in fuel economy.

6. Results

In this section we present the results of our econometric model for aggregate fuel economy for the entire UK car market. The values for the relevant coefficients can be taken as the short run and long run fuel price elasticity of fuel economy. Econometric results of the long run and short run equations are tabulated in Tables 3 and 4, respectively. These results assume symmetric responses of fuel economy to price changes and to the other independent variables.

6.1 Fuel economy of gasoline vehicles

In the long run equation, in (1), the most significant and strongest effects on new car fuel economy are from income and gasoline price (estimate of -0.31; and -0.13). Both coefficients show plausible ranges but only income is highly statistically significant at more than 1% probability. The ECM coefficient is not significant at 10%

[11] Time Series Processor (version 4) and Oxmetrics (version 4) were used to estimate Engle Granger tests and the ADF tests. Full results are available from authors.
[12] Similar models have been applied by other researchers, however, none of the studies reviewed in Table 2 have examined diesel and gasoline fuel economy using this method.

probability level but it is negative, as theory predicts. This coefficient shows a low speed of adjustment revealing that, in the first year 5 % of the adjustment occurs towards the long-run solution,

For consumers with higher incomes, it appears that fuel economy is negatively associated with income in the long run; this effect is significant (Table 3). A 10 % increase in income is linked to a 31 % decrease in liters per 100 kilometers of fuel economy. This indicates that higher incomes allow consumers, over time, to buy more fuel efficient vehicles. The opposite result, however, would be expected after the shift of consumer preferences for larger cars: higher incomes increase consumption per kilometer; this is shown by the short run model in Table 4.

Likewise price effects behave similarly in the long run. The response of fuel economy is negative with an elasticity of -0.13: price increases improve (less litres per km) fuel economy.[13] There is also a small and negative dummy effect (Voluntary Agreement) on fuel economy, in the long run equation. This result shows that new car fuel economy reacts to the standard but by small margin. Fuel economy movements are found to respond mainly to the influence of income followed by fuel price and far less to the dummy.

Table 3: Long run Equation Coefficients For Fuel Economy (gasoline)

Variable	Probability values (Of t-ratios)	Estimated Coefficients	Rsq.=0.71; Obs=33
INTERCEPT	**0.000**	**6.46**	
RPDI	**0.003**	**-0.308**	
PFU	**0.602**	**-0.13**	
STAN (Dummy)	**0.993**	**-2.70E-04**	

Note: Estimated using Oxmetrics V.4. Programs routines from courtesy of Cambridge Econometrics. Using data of 1978-2003 we obtained lower income (-0.38) and price elasticities (-0.40) of fuel economy. Period of observation: 1971-2003.

[13] Model runs of fuel economy, using cost per km (fuel price divides by fuel economy), show price elasticity of -0.34 (insignificant at 10% probability) and an income elasticity of -0.43, (significant at 1% probability). Using cost per kilometer did not show precision in the estimates of fuel economy and so we reject this model.

Table 4: Short Run Coefficients For Co-integrating Fuel Economy Equations (gasoline)

Variable	Probability values: (Of t-ratios)	Estimated Coefficients	Rsq.= 0.32 Obs= 31
INTERCEPT	0.148	-0.18	
RPDI	0.324	0.42	
PFU	0.629	0.06	
FE(-1)	0.040	0.50	
ECM(-1)	0.430	-0.05	

Note: See equations 1 and 2 for definitions of variables shown at the head of each row. All equations are estimated in Oxmetrics. Estimated using Oxmetrics V.4. Period of observation: 1973-2003 with lag terms.

In the short run model, Table 4, the coefficient on price is 86 % smaller than that of income. The analogous relation in the long run equation is lower at 58%. This shows that price is a worse predictor of fuel economy in the short run model. The coefficient on past fuel economy ($FE_{(t-1)}$), in first differences, is statistically significant and positive: past fuel economy increases today's fuel economy (more liters per km). This result is confirmed in Gately (1990) (with an estimate of 0.78) and Small-Van-Dender (2006) (with an estimate of 0.81).

Our estimated (long run) price elasticities of fuel economy lie in the range of values reported in the literature for the UK, OECD, US and others countries (Table 2). One reason for our slightly high elasticities (Tables 3 to 5) is that whereas we use cost per liter of fuels other authors examining the U.S. (Gately (1990), Greene, 1990; and small-Van Dender, 2006) use cost per mile, to estimate price effects on fuel economy.[14]

[14] Our price elasticitiy estimates are below those (upper bound) of Johansson and Schipper, (1997) for fleet fuel economy using different data and technique , while in the range of Gately (1990). Our estimates are below those of Atkinson and Halvorsen (1984), Their data, however, is marked by high gasoline prices hence its high price response. Sweeney (1979) finds a lower price elasticity with data of 1957-1974, a period of largely low gasoline prices. Zachariadis and Clerides (2006) report slightly higher elasticities than our results. Table 2 summarises major studies on fuel economy.

Second, in comparison to other studies we examine more periods of considerable gasoline price volatility. For instance, prices are volatile in the 1999-2003 period. Third in the case of income responses of fuel economy, unlike other studies, we included real personal disposable income instead of per capita income as commonly used to obtain income elasticity of fuel economy.

6.2 Fuel economy of diesel vehicles

We repeated the two-stage error correction model for the case of fuel economy for diesel vehicles, using the analogous variables. Table 5 shows the econometric results of a dynamic model of fuel economy for diesel vehicles for the period 1978-2003, for which diesel vehicles achieved non-trivial market penetration. Results for diesel vehicles show that elasticities for both parameters (price and income) are negative in the long run.[15]. The model performs less well compared to gasoline equations but the price and income effects show the negative impacts on fuel economy, a result found earlier for the gasoline case (Table 3). Dahl (1995, pp. 16) finds an income elasticity of -0.21 (long run) using evidence of 8 studies and so our estimates are close to consensus.

Table 5: Long Run Equation Coefficients For Fuel Economy (diesel)

Variable	(t-ratios) Prob. values	Estimated Coefficients	Rsq.=0.41; Obs.= 26
INTERCEPT	0.000	4.36	
RPDI	0.001	-0.21	
PFU	0.200	-0.13	
STAN (Dummy)	0.077	0.07	

Estimated using Oxmetrics V.4 ; programs routines are a courtesy of Cambridge Econometrics. Period of estimation: 1978-2003 ; dummy=1995-99 is 1, otherwise 0.

Table 6: Short Run Equation Coefficients For Fuel Economy (diesel)

Variable	(t-ratios)	Estimated	Rsq.=0.24;

[15] Model runs, using cost per km, shows an insignificant price elasticity of -0.01 and income elasticity -0.20 (significant at 1% probability). We reject this model given lack of precision in the estimates.

	Prob. values	Coefficients	Obs.= 24
INTERCEPT	0.120	-0.04	
RPDI	0.180	1.22	
PFU	0.460	-0.18	
FE (-1)	0.780	-0.09	
ECM	1	0.05	

Estimated using Oxmetrics; programs routines are a courtesy of Cambridge Econometrics.
Period of estimation: 1980-2003

Income effects, in the short run, turn positive (and elastic) implying that as incomes grow consumers buy (higher ratio of litres per KM) larger diesel vehicles. For instance a profile of diesel vehicle sales shows that diesel penetration is higher in larger cars than in small ones: in the upper medium, executive and MPV and dual purpose vehicle 4X4 (Sport Utility Vehicles) segments. These larger cars recorded a market share of 60% of total sales in 2005, a higher share than that of 1997 (SMMT, 2006, pp. 23). Data also confirms that engine size thus higher fuel consumption, of diesel cars sold, is increasing over time.[16]

In summary, previous studies for fuel economy support our results on the directional effect of the income and price coefficients of long run equations (1) (Tables 3 and 5) and, to some extent, on the magnitude of the fuel economy elasticities found in this paper. A few studies, such as that of Witt (1997), report similar elasticities to ours. Second our price elasticities (long run) are similar for both gasoline and diesel, and surprisingly, fail to reflect the lower efficiency of gasoline engines compared to diesel ones. Third our results show, in agreement with others studies, that income effects can be found to be negative and sometimes positive. Dahl (1995), for example, argues:

"…income elasticity for MPG (miles per gallon) may have changed from negative to positive as the result of higher incomes being used to buy more new cars with higher fuel efficiency.

[16] For example, whereas 178 thousand units in 1800cc^3-3000 cc^3 range in 1996 were sold, by 2005 such figure rose to 670 thousand units; most of which are skewed towards the upper end of diesel engines of new cars. (Dft, 2005, table 9). In short, fuel economy is closely determined by trends in engine size.

But it would also be worth looking into whether the income variable could be picking up a push to smaller and lower fuel using cars as the result of higher auto prices" (Dahl, 1995. pp.23).

Our calculated long run income elasticity (gasoline with -0.31 and diesel fuels with -0.20) values are above the range of international studies for gasoline but within the range for diesel. The negative sign on income elasticity (Table 3) is confirmed by Zachariadis and Clerides (2006); Dahl (1995) and Small and Van Dender (2005). Fourth responses to fuel price and to income, are inelastic.[17]

Interestingly the short run behaviour of fuel economy shows the changes in the profile of car purchases in terms of higher or lower fuel economy. Such changes occur from year to year in the car market. On the other hand, the long run behaviour captures technological change in vehicle engines partly driven by price and income effects, since such changes require many years to emerge.

One limitation, shown by all models, is that these assume symmetric responses (an increase/decrease in price increases/lowers fuel economy in equal proportion) of fuel economy to price changes and to the other independent variables.

6.3 Policy Consequence of the Analysis of New Car Fuel Economy

Policy consequences resulting from our models, lead us to believe that (1) a tighter fuel economy target is required to mitigate national fuel consumption, in lieu of fuel price increases, given that consumers are not sensitive enough to fuel price; (2) that growth in personal incomes appears to lead to improvements (a reduction on the ratio of litres per km) in fuel economy in the long run; and (3) that the Voluntary Agreement on CO_2 emissions reductions has not been sufficiently effective in changing manufacturer behaviour to achieve significant improvements in fuel economy.[18] In early 2007 it was announced that the EU is to introduce mandatory CO_2 targets by 2009. Since 1995 to 2007, the EU Commission has had no other mechanism to persuade car manufacturers to change fuel

[17] Please note that our estimated price and income elasticity are based on data from high gasoline prices (late 1970's early 1980's) and low gasoline prices (early 1970's and 1990s), explaining our different estimates compared to other literature. Our data set is largely dominated by the low energy price period.

[18] Fuel duty (tax on fuel) is already higher than in other OECD/EU nations; it accounts for large proportion of the final price of gasoline. This means that introducing higher fuel taxes is politically difficult as a tool to improve fuel economy. UK Gasoline tax was 100% higher than the EU average tax. UK diesel tax was 95% higher than the EU's average diesel tax in 2001 (based on Newbery, 2005, pp. 25)

economy. In contrast, in the U.S. the manufacturer faces a financial penalty should it fail to meet the mandatory CAFE fuel economy standards (CBO, 2002). Another policy issue is whether the improved fuel economy, by lowering the cost of driving a kilometre, induces drivers to travel further hence consuming more energy. The rebound effects of fuel economy are a major weakness of standards and of any analysis of improved fuel economy that claims that fuel economy, whether determined by the market or by the standard, will lower fuel demand of cars. This issue has not been investigated here.

7. Conclusion

In spite of improvements in fuel economy, the introduction of Voluntary Agreements on CO_2 emissions reductions and high gasoline prices and fuel taxes compared to several OECD economies, total energy demand and total CO_2 emissions of UK private vehicles are not decreasing as desired by policy-makers. Our models of fuel economy capture consumer actions via purchases of higher or lower new car fuel economy. The fuel economy of new cars is found to be inversely linked to gasoline price and to incomes and responds to the Voluntary Agreement on CO_2 emissions in the long run. For gasoline fuels, our models of fuel economy show that there is a long run relationship among fuel economy, real fuel prices, real personal disposable income and the presence of the fuel economy standard. In the long run, the gasoline and diesel equations show wide differences in income elasticity values for fuel economy. Short run responses, for gasoline and diesel, show that at higher incomes consumers will opt for higher fuel intensity as they buy larger vehicles. Similarly, in the short run, there is inertia between past fuel economy and current fuel economy for both fuels. A consistent finding is that demand for fuel economy is price inelastic and income inelastic for both gasoline and diesel cars.

Interestingly the short run behaviour of fuel economy shows the changes in the profile of car purchases in terms of higher or lower fuel economy. The long run behaviour captures technological change in vehicle engines partly driven by price and income effects, since such changes require many years to emerge.

Improvements in new car fuel economy and in the fleet wide fuel economy ultimately shape the evolution of energy consumption. How quickly the improvement

occurs will depend on car sales and rate of vehicle stock turnover which depends on macroeconomic conditions.

One weakness of our analysis of fuel economy is that we can not wholly explain the effect of the introduction of Voluntary Agreement since 1998; but our analysis does show that fuel economy is influenced by the introduction of such Agreement, nonetheless further research is needed in this area. Second, further study should also include (a) data on the fuel economy of 4X4 cars; (b) an explicit analysis of fuel switching from gasoline cars to diesel ones ; and (c) a detailed analysis of fuel economy by vehicle size.

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Appendix

Data Sources:

Most data is sourced from the UK's Department of Transport (DfT) publication *Transport Statistics Great Britain.* Data is also sourced from the Department of Trade and Industry's (DTI) website.

Real Personal Disposable Income
1970:2004
Cambridge Econometrics Ltd. Database

- *Road transport energy use by vehicle type, split by Derv and petrol*
Table 2.6 Road transport energy use by vehicle type, split by Derv and petrol, 1970 to 2003
1970:2004
Dft ((NETCEN) 2005
DTI website: DTI.gov.uk,

-*Energy consumption of road transport (Tonnes of Oil equivalent)*
1970:2004
TABLE 2.1 Transport energy consumption by Type of Transport and Fuel, 1970 to 2005
DTI (2006)

-*Final energy consumption (Tonnes of oil equivalent)*
1970:2004
Table 1.5: Final energy consumption, by fuel, (1) 1970 to 2005
DTI (2006)

-*Emission factors of gasoline and diesel cars*
Defra website: www.defra.gov.uk

-*Vehicle kilometres (billion per year)*
1970:2004
DFt (2005), Transport Statistics Great Britain (2005), Traffic - data tables
Table 7.1

-*Vehicle stock*
1970:2004

TSGB, Table 9.1 Motor vehicles currently licensed: 1950-2004

The data for new car fuel economy (sales weighted) of both gasoline and diesel engines, and of diesel and of gasoline prices is sourced from:
DfT's Transport Statistics Great Britain (TSGB, 2005, 2006). Data prior to 1994, for new vehicle fuel economy, was obtained from Mellor (1993). The data for fuel economy is sales weighted thus avoiding giving undue importance to certain car makes in total car sales. For 1970-77 data we calculate fuel economy assuming the same ratio (3%) between fleet average fleet fuel economy and new car fuel economy in 1977. Actual fuel economy data (1970-77) is thus adjusted downwards using such ratio.

-Fuel economy (l/100km)of new gasoline and diesel cars
1970:2004
TSGB, Table 2.8: Fuel consumption factors for cars and lorries
For 1978-1980 (see Mellor)

-Gasoline and Diesel price (Uk p./liter)
1970-2004
DTI website, Table 4.13 Typical Retail Prices of Petroleum Products 1970 to 2005, Table 4.1.3 (Department of Trade and Industry (DTI), Digest of United Kingdom Energy Statistics (DUKES)
Prices are deflated using the Cambridge Econometrics database on GDP deflators.

-NOx (Nitrogen) Emissions
DEFRA website: www. defra.gov.uk/environment/envrn/gas
Table *6. Estimated emissions1 of nitrogen oxides2 (NOx) by UNECE source category, type of fuel and end user and for large combustion plants (LCPs): 1970 – 2004.*

-Population
Eurostat website: http:/epp.eurostat.ec.europa.eu

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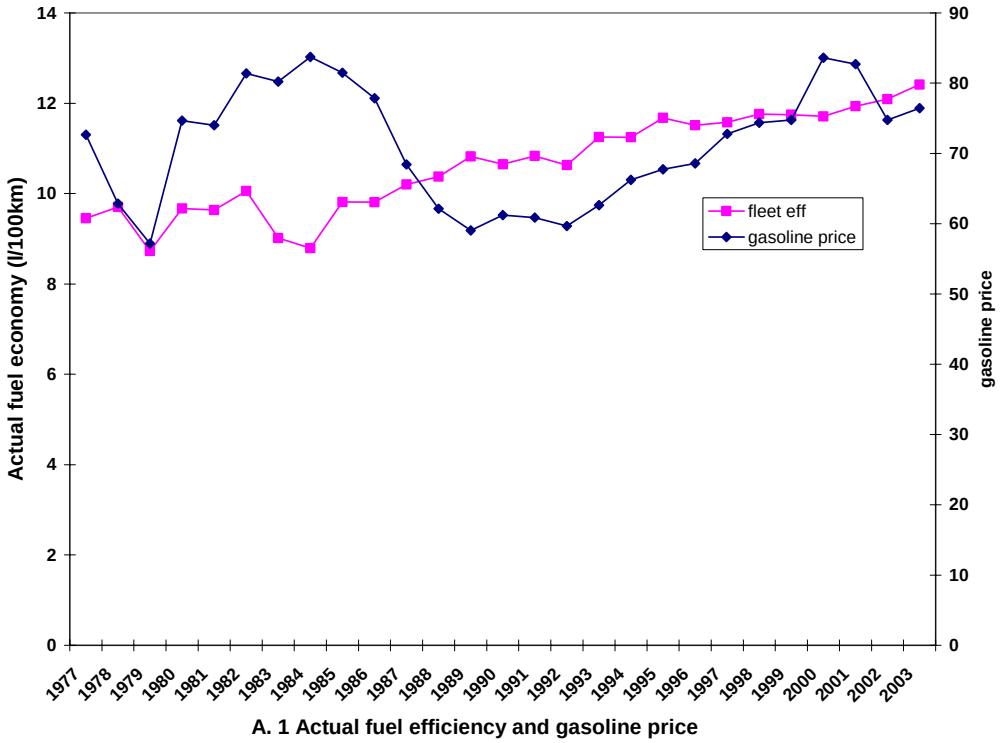
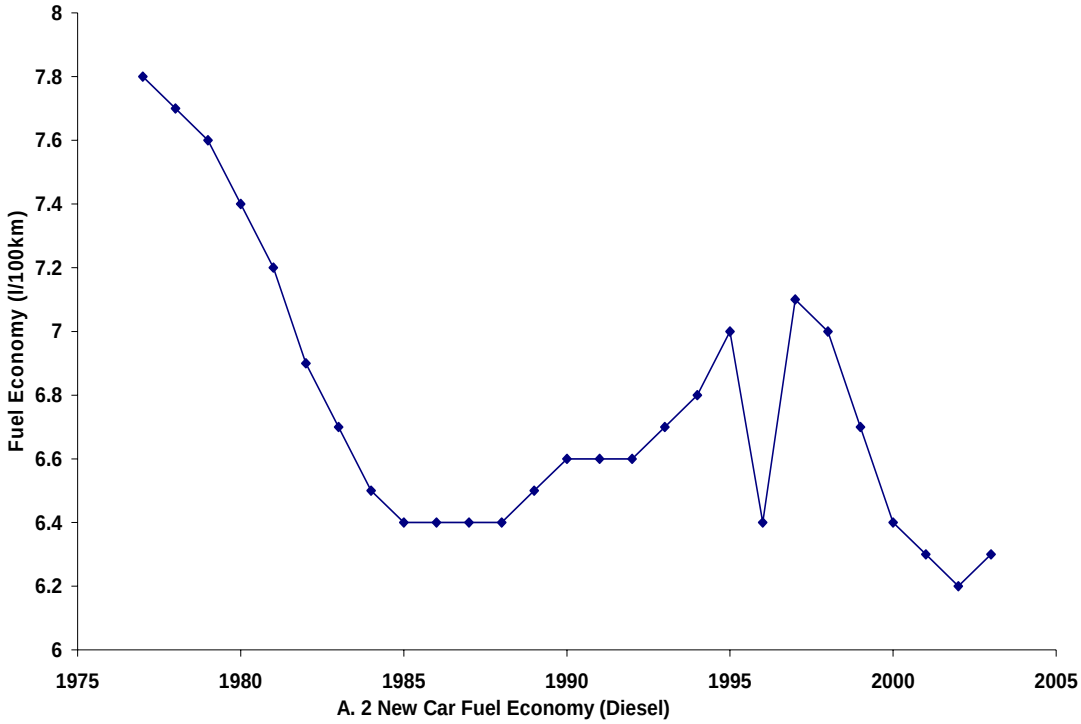
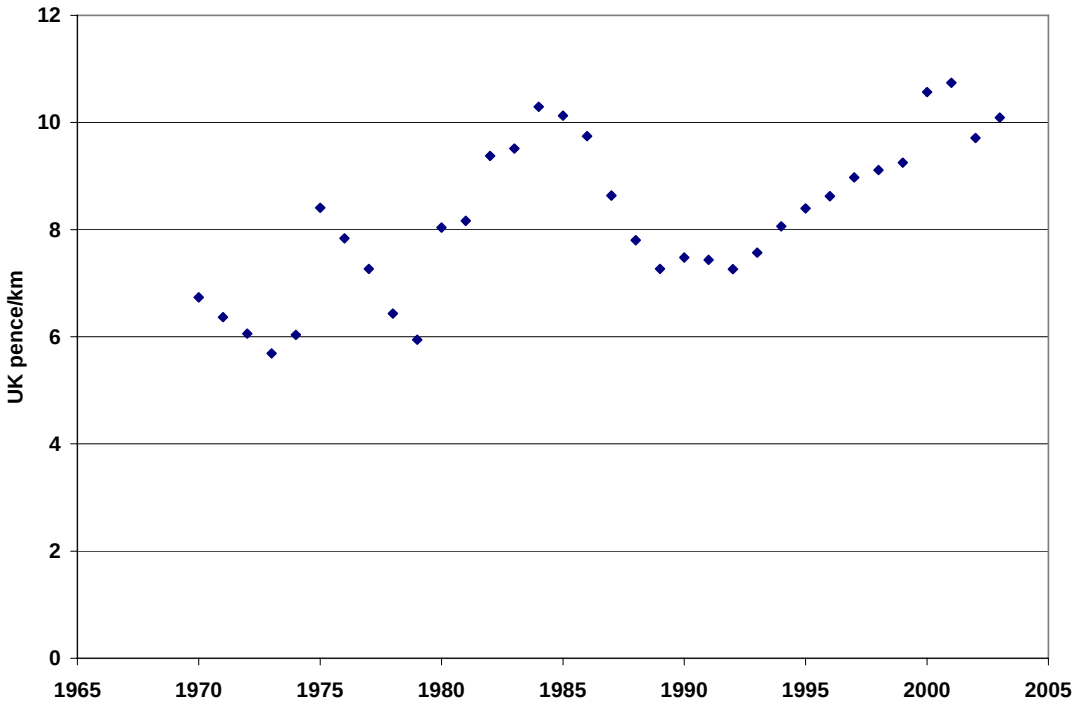
Appendix



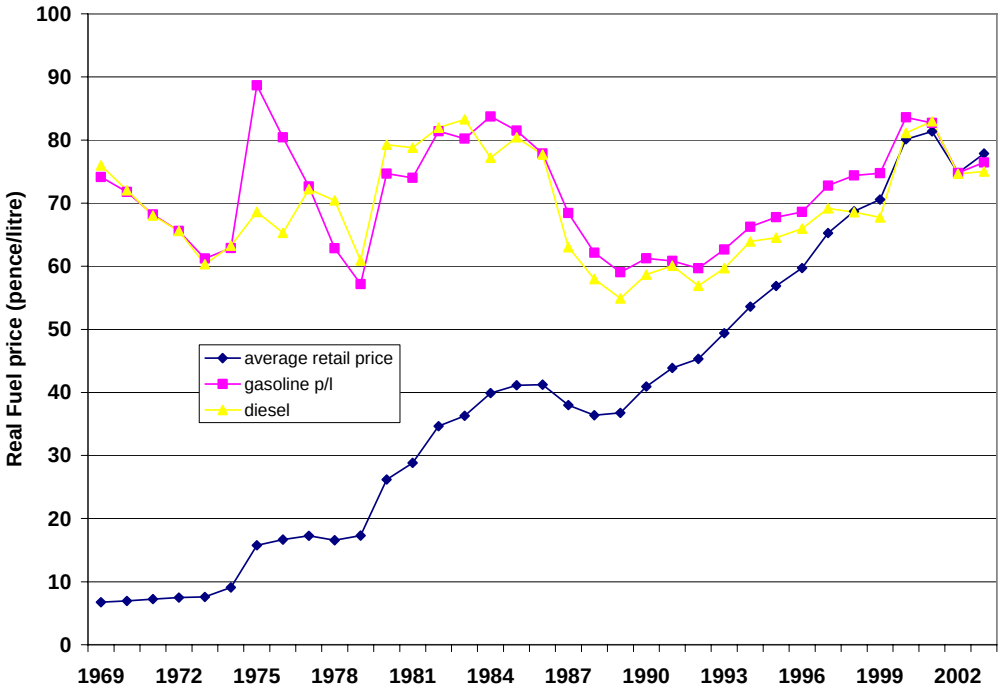
A. 1 Actual fuel efficiency and gasoline price



A. 2 New Car Fuel Economy (Diesel)



A. 3 Cost per Kilometer: gasoline cars



A. 4 Fuel prices