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New vehicle fuel economy in the UK:
Impact of the recession and recent policies

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Note: There will still be some minor changes made to this manuscript prior to final publication.

1. Introduction

In the backdrop of potentially adverse effects of climate change in the future, reduction of greenhouse gas emissions is a major policy goal of the governments in most of the developed world. Among the different sectors of the economy, decarbonizing transport appears particularly challenging. For example, the UK has reduced its total carbon emissions by 22% by 2011 over 1990 emissions, but during the same period transport emissions have reduced by only 2.5% (Department of Energy and Climate Change 2013).[1] Given transport emissions are overwhelmingly governed by the emissions from road transport in most countries, it is crucial to address this area in order to make meaningful contribution toward the overall reduction target. While many technology options for decarbonization of vehicles are being explored by researchers, it appears the current petroleum based vehicle technology will continue its dominance in the near future (National Petroleum Council 2012). As such, addressing new car fuel economy[2] to reduce fuel consumption and carbon emissions has become an important area of academic and policy interest after a long hiatus since the oil shocks of the 1970s. Automobile fuel economy is also important from an energy security perspective, especially due to increasing volatility in fuel prices and continuous geopolitical unrest in the major oil producing regions. Accordingly, recent years have seen the strengthening of the US Corporate Average Fuel Economy (CAFE) standards for light duty vehicles and the legislation of a European Union (EU) wide carbon efficiency standard for automobiles. In addition to the command and control policies such as standards, there are various other policy levers - including the market-based ones - that can affect the fuel economy of the personal vehicle fleet. It is important for policy design purposes to understand the relative impact of the factors affecting the fuel economy of vehicles, such as income, fuel price, standards, car registration duties/taxes, etc. Therefore

[1] Even this reduction masks the fact that transport emissions had generally been increasing until the recession, when travel activity reduced significantly.

[2] Fuel economy is measured in miles per gallon, and is used extensively in the USA and the UK. On the other hand, fuel intensity, measured in litres per 100 km or gallons per 100 miles, is a more readily useful metric for fuel consumption. An improvement in fuel economy means mpg goes up, while an improvement in fuel intensity means l/100km goes down. Fuel efficiency is used somewhat loosely – to engineers it means fuel intensity, but in energy economics literature the term has been used interchangeably with fuel economy as well.

our objective in this paper is two-fold. Firstly, we are interested to know specifically about the impact of recent recession and resulting reduced real income on the fuel economy of the new car fleet in the UK. Secondly, we want to understand the relative magnitude of the impacts of various recent policy initiatives along with the effects of fuel price on new car fuel economy. Unlike previous studies on new car or car stock fuel economy, we use data with a finer temporal resolution and also benefit from a strong variation in the income data (resulting from the recession), which allow us a more robust investigation into the effects of income. Using the results of our econometric model, we also simulate the evolution of the relative impacts of various policy levers, price and income on fuel economy.

This paper is organized as follows. Section 2 briefly discusses the literature highlighting the ambiguous finding on the effects of income. Section 3 discusses the policies undertaken in the UK that could affect new vehicle fuel economy. Section 4 describes the data and their sources, along with the modeling strategy. Section 5 presents the results of the econometric model, discusses their implications and simulates the effects of various policies. Section 6 draws conclusions.

2. Review of the Literature

One of the first studies to model ex-post the impact of the Corporate Average Fuel Economy (CAFE) standards on new vehicle fuel economy was by Greene (1990) in the USA. Using manufacturers' vehicle sales data, he finds that the CAFE standards had twice the influence of fuel prices during 1978 to 1989, when new car fuel economy showed a large improvement in the USA. Aggregate time series studies of vehicle fuel economy often use stock fuel economy, i.e. the average fuel economy of all the cars (or cars + light trucks in the USA) on road although studies focusing on new car fuel economy have started to emerge as well. There is a consensus among these studies that higher fuel prices lead to an improvement in fuel economy or, at worst, no discernible improvements (Klier and Linn 2013, Clerides and Zachariadis 2008, Espey 1996, Johansson and Schipper 1997, Greene 1990). However, the effect of income is ambiguous in literature. For example, Johansson and Schipper (1997), Dahl (1995) and Clerides and Zachariadis (2008) report that an increase in income reduces the fuel economy (of current or new car fleet) in the USA, Canada and Japan, yet Bonilla and Foxon (2009) and Bonilla (2009) find that new car fuel economy improves with increased income in the UK. Clerides and Zachariadis (2008) find that income had no discernible impact, while Ryan et al. (2009) report conflicting income effects for their two models for Europe. [3]

The ambiguous finding on the effect of income on vehicle fuel economy can be important for policy design, especially for the effectiveness of the market-based policies to improve the fuel economy of new cars. A priori, as income rises the marginal utility of income reduces, which would likely make people less sensitive to the running costs of cars and therefore savings from higher fuel economy becomes less important in vehicle use (Greene 1992, Small and van Dender 2007) or purchase decisions. In such cases the income elasticity of fuel economy should be negative. On the other hand, more fuel efficient vehicles are generally more expensive yet the lower marginal utility of a larger income means a lower sensitivity to the higher purchase price as well. This could result in a positive income elasticity, as argued by Johansson and Schipper (1997). The net effect of an income increase via marginal utility thus depends on how people trade-off the additional purchase price against the present value of fuel savings and still remains uncertain. Anecdotal evidence on this from disaggregate studies are inconclusive, too (e.g. Wadud et al. 2010a and 2010b find that wealthier households have more efficient vehicles in the USA, while McMullen and Zhang 2007 and Baker et al. 2011 found the opposite for Texas and Oregon). Also, increasing income can lead to a greater demand for energy-intensive in-car accessories (e.g. air conditioning, power windows and seats, driving assistance technologies, etc.) and thus lower the fuel economy.[4] The combined, net effect of income is still inconclusive and require further empirical investigation.

All of the studies on aggregate, time series fuel economy modeling are more-or-less ‘naturally’ constrained by datasets where income has consistently been increasing over time, barring a few, short recessions. This often does not allow those studies to precisely estimate the effect of income - especially when a time trending variable or a lagged endogenous variable is present in the estimation model, which can result in multicollinearity problems or even spurious correlation (e.g. Clerides and Zachariadis 2008, Johansson and Schipper 1997, Ryan et al. 2009). Bonilla and Foxon's (2009) results for income effect could also be biased toward a positive value because of a lack of control for the voluntary fuel economy targets in the UK during 1978-1985, when fuel economy and income were both increasing. Therefore, our first objective in this paper is to determine the 'net' effect of income on new vehicle fuel

[3] There is a sizeable literature on vehicle choice, where fuel economy enters as a direct or indirect attribute. Also a few studies attempt to model the willingness to pay for fuel economy. Neither considers the aggregate evolution of fuel economy and the effect of various policies or external events on this evolution.

[4] We thank an anonymous reviewer for suggesting the marginal utility based argument here.

economy in order to unravel some of the ambiguity. This would then allow us to simulate the effect of the recession induced loss in income.

The recession in the UK also affords us with observations during a period that is quite different from those used in other studies. Between 2005 and 2013, the economy in the UK grew first, and then showed a sharp drop in GDP, followed by a slow recovery, which makes the drop in income more persistent and visible to the car owners. Similarly retail fuel prices have also risen to a peak not seen till the oil shocks of the 1970s, followed by a sharp fall and then a substantial increase again. Also, a number of UK policies (introduction of fuel duty escalator, restructuring of vehicle excise duty and company car tax, voluntary and mandatory carbon efficiency standard for new cars, etc.) were enacted during the late 1990s and early 2000s which were beginning to have their mark on new vehicle fuel economy, but the impacts of which were not quantified in a comprehensive econometric framework. Our second objective is to quantify the relative impacts of these policy initiatives on new vehicle fuel economy in the UK.

3. Policies affecting vehicle fuel economy in the UK

Fig. 1 presents the evolution of new vehicle fuel economy over the last 30 years in the UK, although a consistent time series is not available from the two government sources: Transport Trends (Department for Transport 2007) and Transport Statistics Great Britain (Department for Transport 2013). The time series data clearly shows a trend of improving fuel economy until 1985 (following the oil shock), a period of stagnation, and then an improvement again from the late 1990s. All of the major shifts can be traced to various government policies that address new vehicle fuel economy directly or indirectly. These policies can affect both the supply side to improve vehicle fuel economy directly, and the demand side to encourage buying of fuel efficient cars.

[Fig. 1 about here]

The history of policies that can affect fuel economy of new vehicles goes far in the UK. Duty (tax) on motor fuel was first levied in the UK as early as in 1909 for fiscal reasons, but in 1993 an escalator was introduced, by which it was set to increase at a rate slightly above the inflation. Concern about greenhouse gas emissions from motor fuel was a major motivation behind the fuel duty escalation in 1993. The escalation formula has since been changed, postponed, frozen, reintroduced or restructured during various years until now. Imposition of fuel duty increases the prices of fuel and encourages consumers to buy fuel efficient cars in order to minimize running costs. However evidence suggests that consumers value only first three years worth of fuel cost savings when buying a car (Greene et al. 2013) and therefore the impact is not as high as it could have been had the consumers been interested in lifetime fuel cost savings from the vehicle.

The first policy initiative to directly improve fuel intensity of new car fleet was undertaken in the late 1970s in response to the two oil price shocks. A voluntary agreement with the car manufacturers on a 10% improvement in new car fuel consumption between October 1978 and October 1985 was widely believed to have been successful in achieving the target two years ahead of the deadline (Sorrell 1992). By the end of October 1985, around 13.2% to 15% improvement in fuel intensity was reported. As oil prices in the global market plummeted, vehicle fuel economy received little attention from the policy makers during the 1980s. Political interest in regulating vehicle fuel economy was renewed in a different form in the early 1990s, through the intentions to regulate carbon emissions from new vehicles. During late 1990s the EU, of which the UK is a member country, entered in a voluntary agreement with the car manufacturers associations in Europe (ACEA), Japan (JAMA) and Korea (KAMA) to reduce sales-weighted carbon intensity by 25% to 140 g/km for new car fleet by 2009. While some progress was made initially, by the mid 2000s it was clear that the voluntary target would most likely be missed by the manufacturers. In 2009, the EU adopted a mandatory new car sales-weighted carbon emissions target of 130 g/km by 2015, although individual manufacturers face different target depending on their existing vehicle sales mix (European Commission 2013a). In order to ease the transition, a phase-in period started in 2012, whereby only a certain share of the manufacturers' new car fleet (65% for 2012, 75% for 2013 and so on) is subject to the regulation. The proposed target for 2020 is 95 g/km, which is currently awaiting legislation. This standard is to be met over entire sales in the EU area, and thus new vehicles in the UK can have higher or lower fuel economy than the rest, depending on the manufacturers' strategy in different EU countries.

In addition, two other significant policy instruments had recently targeted the carbon (and by extension, fuel) intensity of new cars. The first is the Vehicle Excise Duty (VED), which is similar to an annual vehicle use tax. First implemented in 1889, VED is levied on in-use vehicles on an annual basis (Environmental Audit Committee 2008). Between 1920 and 1948, the VED was graduated based on the car's horsepower (which has some relationship with fuel economy), but was later replaced by a flat rate in 1948. As environmental impact of car use became a concern, the VED was differentiated between two groups based on engine size in 1999. It was further restructured in 2001 when new cars were divided into four VED bands depending on their carbon intensity (i.e. cars in higher emitting bands attract a larger VED). While the fees increased in 2006 and 2007, the next major change was in 2009, when the number of emissions bands was increased to thirteen in order to better incentivize the customers to buy more fuel efficient cars.

The restructuring of company car tax in 2002 also had a direct impact on car purchase and use behavior of the businesses in the UK. The companies in the UK are taxed for their supply of vehicles to employees for personal use. Prior to 2002, the tax base for company cars was estimated using a fixed percent (35%) of the prices of the cars, but from 2002, this was made variable, depending on the carbon efficiency rating (along with other changes on the treatment of business mileage). Given company cars make up a large share (typically around half) in the new vehicle market, such a reform was expected to have substantial impact on carbon emissions and fuel economy. Indeed, HM Revenue and Customs (2006) find that the reform had saved 0.2-0.3 Mt of carbon in 2005, and was projected to save 0.35-0.65 Mt in 2010. Note however, this saving is not a result of buying fuel efficient vehicles alone, but also of lower business mileage and switching from company car to private cars.

In addition to these policies, following the recession in 2008, a vehicle scrappage scheme was introduced in 2009 for a year. While the primary purpose was to stimulate new car sales, an important objective was to replace older, more polluting vehicles with newer, more fuel efficient ones. During its ten months of operation, the carbon intensity of the cars bought under the scheme was around 45 g/km better than the scrapped ones (Lane 2009). However, the overall environmental benefits of such vehicle scrappage schemes are often debated in the academic literature, especially since there was no requirement to buy a fuel efficient car under the UK scheme. Table 1 below summarizes the salient features of these policies.

[Table 1 about here]

4. Data and Methods

Average fuel economy for new car fleet in the UK is available from the UK government sources since the 1970s, but that statistics include only petrol vehicles. Use of such data will mask the impact of diesel cars, which currently enjoys a large market share among new cars in the UK (over 50% as of December 2012). Combined carbon intensity of new car fleet is also available annually from 2001 and quarterly from 2003 from the UK Government sources. We, however, use a dataset with a finer time resolution – monthly – from the Society for Motor Manufacturers and Trade (SMMT). This dataset provides average fuel economy, weighted by registration volume, of newly registered cars in the UK on a monthly basis from 2005. Although this results in some loss of information on a longer time period, the monthly frequency could allow uncovering of important short-run insights. Also, as discussed earlier, 2005-2012 is a period of significant changes in many of the explanatory factors, offering a richer variation in the variables than the earlier annual datasets. In order to proxy income, quarterly per capita expenditure[5] data is collected from the Office for National Statistics (2013): these were interpolated to get monthly values.[6] Monthly average diesel and petrol prices are from AA monthly fuel price reports from 2005 to 2012 (AA 2013). All the nominal monetary variables have been deflated using the consumer price index. The variables are presented graphically in Fig. 2.

[Fig. 2 about here]

We include in our model a time trend to include the impact of prior policies on new car fuel economy. It is clear that the new car fuel economy has been improving since early 2001. Since our dataset starts from 2005 and a number of policies were implemented earlier, the time trend captures the combined effect of these policies, primarily the EU wide voluntary emissions agreement, and earlier reforms in VED and company car tax. Although vehicle sales show a strong seasonality, such seasonality is not obvious for new car fuel economy. However, the new car fuel economy is directly dependent on the characteristics of the vehicles purchased, which could have a seasonal pattern depending on the timing of business and personal purchases. Also unveiling of new models, which has a seasonal pattern too, can affect monthly new vehicle fuel economy. We therefore include monthly dummies to capture the presence or absence of such a seasonal pattern.

Given the widespread media reports about the success of the scrappage program in improving fuel economy, we include a dummy variable to test the effect (if any) of the vehicle scrappage program. A priori, a scrappage program without any fuel economy target for the new vehicles should not affect the fuel economy of the 'new' vehicle fleet.

The restructuring of VED into thirteen bands and the EU-wide legislation of a mandatory carbon standard were both confirmed in early 2009. The simultaneity of the two variables thus makes it difficult to separate their individual effects through binary dummy variables. We note that the impacts of the changes in VED and mandatory fuel economy standards are different in nature, which allows us to develop an innovative strategy to model their individual impacts. Although the mandatory standard does not come into effect until 2012, the vehicle manufacturers plan ahead and start manufacturing and marketing newer, fuel efficient models much earlier. This would most likely cause a gradual

[5] Expenditure better reflects lifetime income (Friedman 1957) and accordingly expenditure has been extensively used in both aggregate and disaggregate studies (e.g. Archibald and Gillingham 1980, Wadud et al. 2009).

[6] We also used the quarterly values for the corresponding months, but specification tests rejected those models.

improvement in carbon efficiency, and a gradual divergence from the baseline trend in fuel economy, rather than a step-change in 2012. In order to capture this gradual transition of new vehicle fuel economy, we use an interaction between time and a dummy from 2009. Also, although the EU wide standard was approved in the European Parliament in 2009, by June 2007, the Ministers have agreed in principle about the mandatory standard and a strategy document was published by the European Commission (European Commission 2013b). Therefore, in an alternate specification, we utilize July 2007 as the start point of the interaction dummy.[7]

The impact of VED restructuring of 2009 is expected to be different. The restructuring is a demand signal and primarily changes the fleet average fuel economy by changing the market share of the different types of cars sold. This impact is rather instantaneous since the buyers who are sensitive to the changes in the excise duty can respond immediately. We therefore believe a step change in new vehicle fuel economy is an evidence of the impact due to changes in the VED. This can be captured by a regular dummy variable.

Data on new car characteristics suggest that the composition of new vehicles has changed during the study period. This change is a result of not only inherent changes in consumer taste, but also because of the policy induced changes in consumer's new vehicle purchase habits, as well as manufacturers' response to the policy initiatives and other market signals. Inclusion of vehicle characteristics and fuel types in the regression model would likely further improve the model fit, however, since the changes in the composition of new car characteristics or fuel choice are themselves 'responses' to the policy variables, we do not include these characteristics as explanatory factors in our model. For the same reason, we do not include a sales-weighted fuel price and use diesel price to proxy for a general rise and fall in fuel prices. Petrol and diesel prices are highly correlated (correlation coefficient above 0.98), although the ratio of petrol to diesel prices do not remain constant during our sample period. This can have an impact on the comparative share of new diesel and petrol vehicles sold, which can directly affect the combined fuel economy, our dependant variable. Therefore we include the ratio of petrol to diesel prices as an explanatory factor in our econometric model.

Given the choice of our explanatory factors above, our model has the following generic specification:

$MPG = f(INC, DPRC, PDRAT, TIME, VED, STD, SCRAP, MON)$

where, MPG = fuel economy in miles per gallon

[7] We do not follow Small and van Dender's (2007) approach of using a difference between 'standard' and current fuel economy, since the standard is not 'binding' as yet in Europe.

INC = real per capita GDP/expenditure

$DPRC$ = real diesel price

$PDRAT$ = ratio of petrol to diesel price

$TIME$ = time trend

VED = step dummy from 2009, to represent the effects of changes in VED

STD = interaction of dummy and time from 2009 ($STD09$) or 2007 ($STD07$), to represent EU wide carbon standard

$SCRAP$ = step dummy for vehicle scrappage scheme

MON = monthly dummies

We opt for a log-linear constant elasticity specification for our model. Given the time series nature of the data, we utilize an Autoregressive Distributed Lag (ARDL) model. Our final specification is:

$$lnMPG_t = \alpha + \beta_i \sum_i lnMPG_{t-i} + \gamma_j \sum_j lnINC_{t-j+1} + \delta_k \sum_k lnDPRC_{t-k+1} + \theta_l \sum_l lnPDRAT_{t-l+1} + \tau TIME_t + \lambda SCRAP_t + \varphi VED_t + \kappa STD_t + \mu_m \sum_m MON_{t,m} + \varepsilon_t$$

where j, k and l are at least 1 and their lengths are chosen using specification tests such that ε_t is not serially correlated and is normally distributed.[8]

5. Results and Discussion

Table 2 presents the Ordinary Least Squares (OLS) parameter estimates and model fit diagnostics for two models with alternate dummy-time interactions for EU-wide emissions standard. Model 1 utilizes the time-dummy interaction from 2009, and specification tests (e.g. Breusch-Godfrey Lagrange multiplier test, Durbin-Watson test or Durbin's alternative test for serial correlation in errors, Lagrange multiplier test for ARCH effect in errors, Bartlett's white noise test of errors, Ramsey's omitted variable tests) show that the appropriate specification has 2 autoregressive lags of the dependent variable, and no other lags of the independent variables (Model 1). In this sense, our model reverts to a partial stock adjustment model rather than an ARDL. However, there are some concerns about potential omitted variable bias in this model, as seen by Ramsey's RESET test results in Table 2. Model 2 uses the alternate time-dummy interaction for EU-wide carbon emission standard from July 2007. Dynamic specifications for different lags of dependent and independent variables with this variable were inadequate (mostly

[8] We do not consider cointegration issues since, although we have 96 data points, they refer to only 8 years of time, which we think is not suitable for the longer term cointegration modelling. Also, we expect a structural break in our dependent variable, MPG, especially in response to the EU-wide carbon standard. The unit root tests for stationarity have a propensity to accept the presence of unit root in these circumstances.

suffering from autocorrelation or ARCH problems) and our preferred specification is a static model. Specifically, Model 2 performs better than Model 1 in the omitted variable test and has better adjusted R^2, AIC and BIC scores. Given the marginal hint of heteroskedasticity (reject the null of no ARCH at 95% level, but cannot be rejected at 90% level) in Model 2, we correct the OLS standard errors for heteroskedasticity using the Newey-West method. Our discussion below is based on Model 2, although we note that Model 1 also supports similar findings, with minor differences in statistical significance.

[Table 2 about here]

The statistically superior performance of Model 2 indicates that the effect of EU-wide mandatory standard is better predicted by the 2007 dummy-interaction than the 2009 dummy-interaction. Thus, manufacturers possibly did not wait until the mandatory standard was legislated in the European Parliament and acted earlier to bring in more fuel efficient cars. This is not surprising given the arrangements of the earlier voluntary agreement. It was clarified during the voluntary agreement that if the manufacturers had failed to meet the voluntary emissions target midway during the time limit, then the European Commission would intervene to impose the mandatory standard. The manufacturers possibly took the agreement among the EU environment ministers and the publication of European Commission strategy as the confirmation they needed and started bringing about changes in their vehicle mix.[9]

Table 2 reveals a statistically significant time trend indicating that new car fuel economy has been improving over the years, as a result of policies undertaken before our sample time period. As explained earlier, these policies potentially include the earlier EU wide voluntary agreement on carbon emissions and the restructuring of company car taxes and VED in early 2001. Obviously, there could also be exogenous technological changes which could have driven these improvements, although the stagnation of fuel economy between mid 1980s to late 1990s indicates that such effects may not have been substantial.[10] At best, our dummy variable captures primarily the effects of the pre-2005 policies, while at worst it captures the combined effects of those policies and exogenous technological changes. On average, new vehicle fuel economy was increasing by 0.12% every month or 1.44% every year, which is equivalent to 0.69 mpg improvements a year at the sample mean fuel economy of 47.7 mpg.

[9] We have also attempted estimating a model where the manufacturers started bringing in more fuel efficient vehicles from 2005 in anticipation of the mandatory standard, but were unable to find one that satisfies the necessary specification tests.

[10] This does not mean that fuel efficiency of 'engines' did not improve during the period, but those improvements were possibly countered by more powerful and larger vehicles and other power consuming features on board.

The price of fuel, proxied by diesel price,[11] has a positive and statistically significant impact on fuel economy, which is expected. Numerical results reveal that every 1% increase in fuel prices improve the new car fuel economy by 0.018% in the short run. Bonilla and Foxon (2009) reports a long run elasticity of 0.26, Witt (1997) finds it to be between 0.17 and 0.30 while Clerides and Zachariadis (2008) find a much smaller elasticity of 0.079. On the other hand, Klier and Linn's (2013) simulation results for the UK translate into a short run elasticity of new vehicle fuel economy of 0.01. Our short run elasticity thus sits within the bounds of Klier and Linn (2013) and Clerides and Zachariades (2008). This is equivalent to an improvement of around 0.09 mpg for every 10 pence/litre increase in real (2005) fuel prices. Since car purchase behavior can depend on past experience and future expectation of fuel prices, instantaneous prices may not always be the best variable representing fuel prices. We therefore tested with lags of price and average of last 3 and 6 months prices to accommodate the effect of past fuel prices (which helps build expectations of future prices as well) in fuel economy decisions, but all of these models came short in the specification tests, in both static and dynamic forms.

The parameter estimate for ratio of petrol to diesel prices is statistically insignificant, indicating that the fuel price differential, at current levels, did not affect the market share of new diesel and petrol vehicles sufficiently to capture an impact on average fuel economy of new car fleet. Our results thus appear in agreement with Schipper and Fulton's (2013) suggestion that only 5% of carbon reduction from new cars in Europe is due to changes in petrol and diesel market share.[12] Also, unlike the rest of Europe, diesel prices in the UK are higher than petrol prices, therefore fuel price differential does not play as big a part in the decision to switch from petrol to diesel (although it may have deterred an even larger switch).

We find that an increase in income has a large detrimental effect on new vehicle fuel economy, with a short run elasticity of -0.214. This supports the hypothesis that at higher income fuel economy becomes relatively less important in vehicle purchase decisions and that the demand for fuel consuming accessories (power wheel and seats, air conditioning etc.) increases. Our results therefore support similar results in the USA and contradict the recent studies in Europe and the UK. As described earlier, we believe the contradiction stems from the limitations in the data (gradually increasing income) or model specification (lack of appropriate control) in the earlier studies in Europe and the UK. Still, the persistence of the recent recession is unique and it implies that we cannot completely rule out the

[11] The choice of diesel price over petrol price is because it is less correlated with diesel to petrol price ratio. Alternate specifications using petrol price also results in similar findings.

[12] Note that carbon efficiency comparison is trickier than fuel efficiency comparison. Although diesel engines have better fuel economy than similar sized petrol ones, diesel fuel is more carbon intensive. Therefore the carbon efficiency gains due to a switch from petrol to diesel are less than the fuel economy gains of such a switch.

possibility that the structural relationship between income and new vehicle fuel economy may have changed recently.

The parameter estimates for the interaction of time and dummy for EU emissions standard, $STD09$ or $STD07$, and for the dummy for restructuring of VED, are both independently statistically significant, indicating our strategy of separating the two effects using a step and an interaction dummy worked well (even for $STD09$ in Model 1 where the effect of multicollinearity was expected to be the worst). Parameter estimate for $STD07$ (or $STD09$ in Model 1) is positive, as expected, and supports the hypothesis that new vehicle fuel economy had further improved over the already upward time trend. On average, the fuel economy improvement in new cars is an additional 2.28% a year since 2007, which is equivalent to 1.09 mpg a year at our sample mean mpg as a result of the mandatory carbon emissions standard. This is not surprising – earlier studies on CAFE standards in the USA also showed that the standard had large impact on new vehicle fuel economy (Greene 1990). VED also has a positive parameter estimate, providing evidence of a step change in the new vehicle fuel economy due to VED restructuring of 2009. VED restructuring in 2009 can be associated with a 0.84% change in new vehicle fuel economy in the UK, which is equivalent to an improvement of 0.40 mpg on average. Giblin and McNabola's (2009) report that the changes in Irish VED structure improves carbon intensity by 3.3% - 3.8% in the long run, although the results are not comparable with ours because of differences in countries, VED structure, and modeling methods - especially ours is a revealed preference time series study, whereas theirs is a simulation prediction from a disaggregate vehicle choice model.

The effect of vehicle scrappage (through dummy $SCRAP$) on new fleet fuel economy is statistically insignificant at 95% confidence level. The result may appear counter-intuitive at first since the cars bought under the scrappage programme were, on average, smaller and had better carbon efficiency than the rest of the new car fleet during that period, a point well publicized in the media. However, if these smaller new 'replacement' cars represent a similar share of small cars as in other years in the new car market, then the changes in 'average' fuel economy of the whole new fleet may not be large enough to be picked up by the $SCRAP$ dummy. Note that in Model 1 also, the parameter estimate for the car scrappage programme is statistically insignificant. Also, the scrappage scheme did not offer any specific incentive to buy cars that were 'more' efficient than the 'average' new car, which would have much improved new fleet fuel economy over the baseline improvements already taking place.

Some seasonality is observed in the monthly new car fuel economy as evident from the statistical significance of the some of the monthly dummies. Taken together they are jointly significant and improve the model fit as well. The seasonality possibly arises due to the differences in the share of private and fleet/company cars and the timing of the arrival of new car models in the market, as discussed earlier.

The parameter estimates for different explanatory factors in our model gives elasticities or semi-elasticities directly, but do not show their individual absolute impact during 2005-2012. In order to understand the contribution of different variables to new car fuel economy in the UK, we undertake a simulation exercise. Fig. 3 presents six panels where the model predictions of new car fuel economy for our dataset are plotted against time in solid blue. The dashed red lines present predictions when one of the explanatory factors is kept frozen during the entire period. Therefore, the difference between the two lines shows the absolute contribution of that variable on new vehicle fuel economy. It is clear that the major contributors to fuel economy improvements are the EU-wide mandatory carbon efficiency standards (panel a) and the combination of pre-2005 policies such as voluntary standards, company car tax reform, EU-wide voluntary carbon efficiency standards and a natural exogenous technology trend (b). The impact of VED restructuring (c), income (d) and prices of fuel (e) during the past eight years were modest by comparison, although their combined effect is not negligible. In panel (f), we present a 'what-if' scenario where income is frozen at its maximum value in our dataset, in November 2007, just before the onset of the recession. Panel (f) therefore shows the evolution of new vehicle fuel economy, if the recession had not occurred. Clearly, the effect of the recession is substantial, although still much smaller than that of the mandatory standards. Thus the EU-wide mandatory carbon standards had a larger relative impact in improving new car fuel economy in the UK, although this does not necessarily result in an equivalent saving in fuel or carbon emissions because of potential rebound effects, however small. On the other hand, some of the demand side initiatives will likely have a relatively larger impact on total fuel or carbon consumption through affecting driving distances and number of trips.

[Fig. 3 about here]

6. Conclusions and Policy Implications

We utilized a monthly dataset on new vehicle fuel economy to understand how they have evolved in the UK from 2005 to 2012. This is an interesting period due to major changes in some of the factors that affect new vehicle fuel economy. The rapid fall and stagnation of income, the rapid rise and fall of fuel prices, and a number of policy changes during the period required careful econometric modelling in order to disentangle the effects. Contrary to recent studies in the UK and Europe, our results show that new vehicle fuel economy in the UK decreases as income rises, which is in line with similar findings in the USA and Canada.

Our findings have important policy implications. We infer that the recent improvement in new vehicle fuel economy in the UK is largely a result of EU wide carbon emissions standard although the persistent recession had a small but significant role. As such there is a risk that once the economy starts to grow consistently again, demand for more fuel efficient new vehicles may start to diminish. This indicates that demand side policies (VED restructuring, fuel duty escalator, etc.) need to consider the potential adverse effects of increasing income on fuel economy. Especially the impact of income is larger on reducing new vehicle fuel economy than the impact of fuel prices on improving it. Variations in the ratios of petrol to diesel prices did not appear to affect new vehicle fuel economy, indicating differences in fuel prices, at least at the current level of small differences, did not significantly affect the switch from petrol to diesel or vice versa in the UK. However, we do note that lower diesel prices in the rest of Europe may have contributed to higher diesel share in those countries.

We also show that, while demand side policies such as VED restructuring had clear positive impact on improving new car fuel economy, the impact is smaller than the mandatory carbon standard. The relatively smaller effects of VED structuring (and fuel prices) does not necessarily mean standards are ‘better’ than the pricing policies, but possibly reflects the relative aggressiveness of the implemented policies and standards, e.g. a larger duty differential between the VED bands could have had a relatively larger impact on new vehicle fuel economy. We can, however, conclude that in order to bring about the same changes in new vehicle fuel economy as brought about by the mandatory standards, fuel prices would have had to rise by an impractically large amount, from an already high base price.

As expected, but contrary to popular media reports, the scrappage scheme did not put any significant dent on average ‘new’ vehicle fuel economy. While the vehicle scrappage programme did reduce carbon emissions by replacing older less efficient vehicles by newer more efficient ones, linking the scrappage schemes specifically to purchasing new vehicles with above average fuel economy could have had some impact on carbon or fuel savings from the replacement vehicles. Such a linked policy has the risk that some old vehicles are not traded at all (where the replacement car would have been less fuel efficient than the ‘average’ new car) – therefore further work needs to be done in this area to identify the optimum strategy.

There are still some limitations in our work. VED restructuring could have had a small gradual impact which could not be disentangled from our emissions standard impact. Similarly, if there were any 'step' changes in new vehicle fuel economy due to the EU-wide emissions standard, that is subsumed in the VED impact. However, we believe both these effects, if they had occurred, would be small in magnitude and should not change our conclusions. Also, we worked on an aggregate model of new vehicle fuel economy. An important area that requires further investigation is the heterogeneity in the income and price effects among different socio-economic groups along the lines of Wadud et al. (2009) or in a vehicle choice modeling framework, since demand side policies would work better once we know the differences (if any) and design the policies accordingly.

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Tables

Table 1. Demand and supply side policies that affect new vehicle fuel economy in the UK

Policy start and duration	Policy	Comments
1909-date	Fuel duty	Implemented for fiscal reasons. Affects demand for fuel economy through higher fuel prices. Differential duties for petrol and diesel also affect new fleet fuel economy as diesel is more fuel efficient.
1993-date	Fuel duty escalator	Mitigating carbon emissions was a major objective. The escalator has been frozen, modified, postponed, reintroduced over various years.
1978-1985	Voluntary target of 10% reduction in new vehicle fuel intensity	Directly addresses fuel economy of new vehicles. Achieved the target 2 years before the deadline. The measurement of fuel intensity was not sales-weighted, but was model average.
1995-2007	EU-wide voluntary agreement on improving carbon efficiency of new vehicles	Directly addresses fuel economy of new vehicles. Target date was 2009, but was replaced by mandatory carbon efficiency standard.
1999-2001	Vehicle excise duty based on engine size	First attempt at restructuring VED to include environmental performance into consideration.
2001-date	Restructuring of VED based on carbon emissions	The number of VED bands changed over time, starting from 4 in 2001 to 13 from 2009. The duty amount also changed.
2002-date	Restructuring of company car tax	Affected the carbon efficiency of the vehicles bought by businesses and fleet.
2009-2010	Vehicle scrappage programme	GBP 2000 subsidy toward buying new vehicles was not linked to vehicle economy.
2009-date	EU wide carbon efficiency standard for new vehicles	Directly affects fuel economy of new vehicles.

Table 2. Parameter estimates for the model (standard errors in parenthesis)

	Model 1	Model 2 (preferred)
Parameter estimates		
MPG-lag 1	0.2234 (0.1091)**	
MPG-lag 2	0.2859 (0.1088)***	
Income/expenditure	-0.2278 (0.0804)***	-0.2144 (0.0566)***
Diesel price	0.0218 (0.0101)**	0.0183 (0.0079)**
Ratio of petrol to diesel price	-0.0478 (0.0360)	-0.0162 (0.0191)
Dummy for VED restructure	0.0082 (0.0049)*	0.0084 (0.0040)**
Dummy-time interaction for EU standard – $STD07$		0.0019 (0002)***
Dummy-time interaction for EU standard – $STD09$	0.0004 (0.0002)**	
Dummy for scrappage	0.0025 (0.0024)	0.0036 (0020)*
Time	0.0010 (0.0002)***	0.0012 (0.0001)***
Dummy for February	0.0049 (0.0028)*	0.0046 (0.0028)*
Dummy for March	-0.0102 (0.0027)***	-0.0074 (0.0019)***
Dummy for April	-0.0037 (0.0025)	-0.0021 (0.0020)
Dummy for May	-0.0035 (0.0026)	-0.0042 (0.0022)*
Dummy for June	-0.0059 (0.0024)**	-0.0057 (0.0019)***
Dummy for July	-0.0007 (0.0024)	-0.0013 (0.0017)
Dummy for August	0.0080 (0.0026)***	0.0077 (0.0023)***
Dummy for September	-0.0064 (0.0030)**	-0.0035 (0.0019)*
Dummy for October	-0.0035 (0.0025)	-0.0004 (0.0022)
Dummy for November	-0.0026 (0.0025)	-0.0018 (0.0019)
Dummy for December	-0.0105 (0.0024)***	-0.0092 (0.0024)***
Constant	3.6296 (1.0231)***	5.4538 (0.4597)***
Model fit statistics		
Estimation method	OLS	OLS with Newey-West correction
Adjusted R^2	0.9973	0.9978
AIC	-737.523	-775.83
BIC	-684.114	-727.104
Ramsey’s reset test for omitted variables	2.26 (p=0.089)	0.92 (p=0.436)
Breusch-Godfrey test for residual autocorrelation	1.415 (p=0.234)	0.003 (p=0.955)
Lagrange multiplier test for ARCH effects	1.657 (p=0.198)	2.986 (p=0.084)
Durbin Watson test for autocorrelation		1.983
Durbin's h test for autocorrelation	1.100 (p=0.294)	
Shapiro-Wilk test for residual normality	z=-0.548 (p=0.708)	z=0.722 (p=0.235)
Bartlett's white noise test for residuals	0.685 (p=0.736)	0.788 (p=0.564)
N	94	96

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Figures

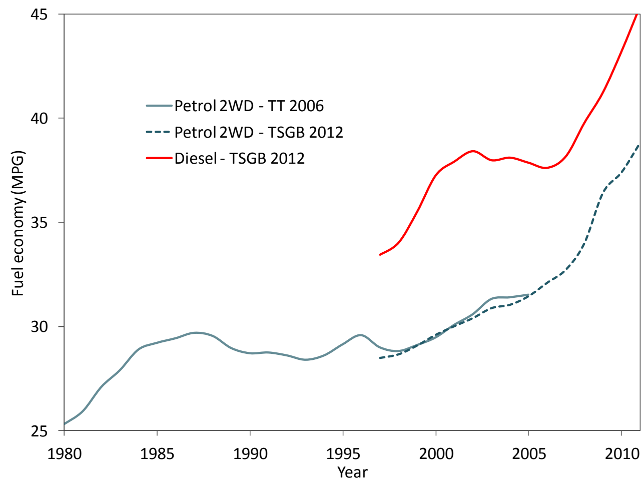

Fig. 1 Annual average new car fuel economy in the UK, 1980-2011 (TT 2006 = Transport Trends 2006, TSGB 2012 = Transport Statistics Great Britain 2012)

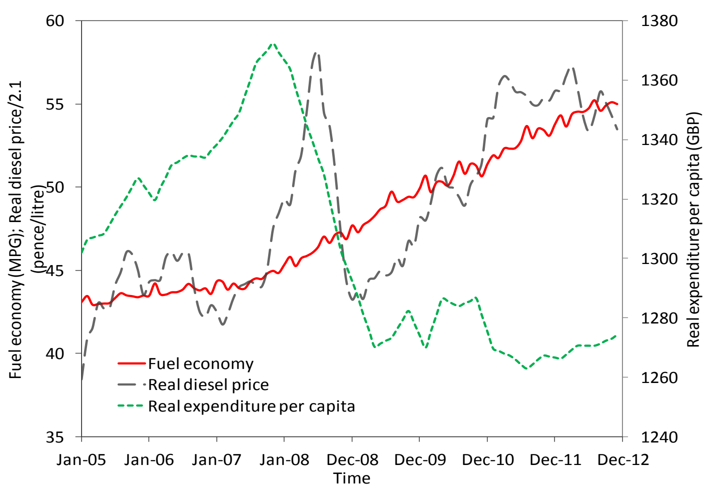

Fig. 2 Evolution of new vehicle fuel economy, real diesel prices and real per capita expenditure in the UK

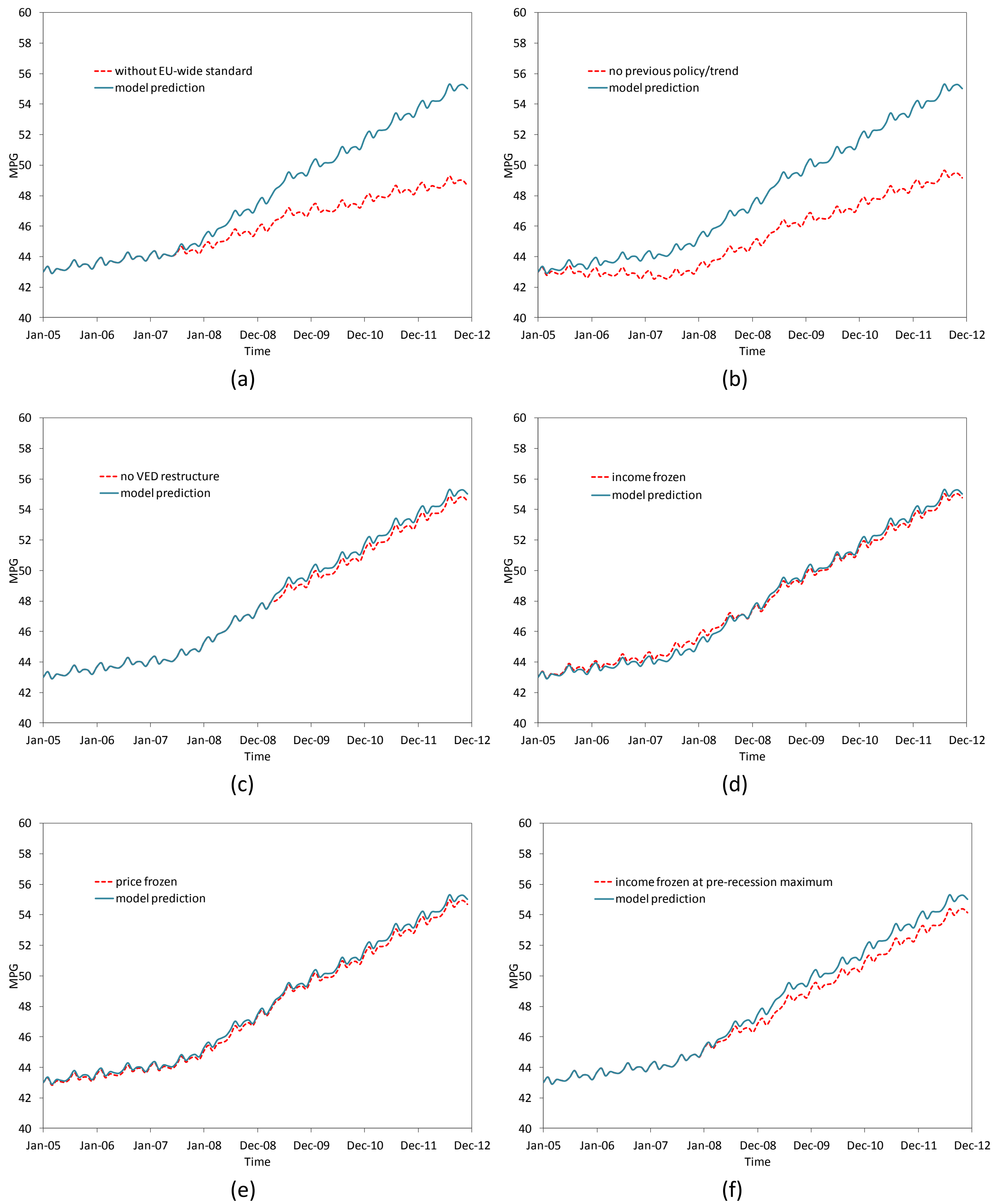

Fig. 3 Effect of different factors on new car fuel economy in the UK: (a) mandatory EU-wide carbon standard, (b) prior policies of EU-wide voluntary carbon standard, VED restructuring, company car taxes, etc., (c) VED restructuring of 2009, (d) income, (e) fuel price, (f) income frozen at pre-recession value