THE ROLE OF FISCAL CAR PURCHASING INCENTIVES IN A FUTURE LOW CARBON TRANSPORT SYSTEM

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ABSTRACT

The transition to a low carbon transport world requires a host of demand and supply policies to be developed and deployed. Pricing and taxation of vehicle ownership plays a major role, as it affects purchasing behavior, overall ownership and use of vehicles. There is a lack in robust assessments of the life cycle energy and environmental effects of a number of key car pricing and taxation instruments, including graded purchase taxes, vehicle excise duties and vehicle scrappage incentives. This paper aims to fill this gap by exploring which type of vehicle taxation accelerates fuel, technology and purchasing behavioral transitions the fastest with (i) most tailpipe and life cycle greenhouse gas emissions savings, (ii) potential revenue neutrality for the Treasury and (iii) no adverse effects on car ownership and use.

The UK Transport Carbon Model was developed further and used to assess long term scenarios of low carbon fiscal policies and their effects on transport demand, vehicle stock evolution, life cycle greenhouse gas emissions in the UK. The modeling results suggest that policy choice, design and timing can play crucial roles in meeting multiple policy goals. Both CO_2 grading and tightening of CO_2 limits over time are crucial in achieving the transition to low carbon mobility. Of the policy scenarios investigated here the more ambitious and complex car purchase tax and feebate policies are most effective in accelerating low carbon technology uptake, reducing life cycle greenhouse gas emissions and, if designed carefully, can avoid overburdening consumers with ever more taxation whilst ensuring revenue neutrality. Highly graduated road taxes (or VED) can also be successful in reducing emissions; but while they can provide handy revenue streams to governments that could be recycled in accompanying low carbon measures they are likely to face opposition by the driving population and car lobby groups. Scrappage schemes are found to save little carbon and may even increase emissions on a life cycle basis.

The main policy implication of this work is that in order to reduce both direct and indirect greenhouse gas emissions from transport governments should focus on designing incentive schemes with strong up-front price signals that reward ‘low carbon’ and penalize ‘high carbon’. Policy instruments should also be subject to early scrutiny of the longer term impacts on government revenue and pay attention to the need for flanking policies to boost these revenues and maintain the marginal cost of driving.

Keywords: transport policy; greenhouse gas emissions; purchase tax; road tax; feebate; scrappage rebate; cars; life cycle analysis

1 INTRODUCTION

1.1 Background

Transport is consistently deemed to be the most difficult and expensive sector in which to reduce energy demand and greenhouse gas (GHG)[1] emissions (HM Treasury, 2006; Kopp, 2007). Typically, the diffusion of advanced vehicle technologies is perceived as the central means to decarbonize transport. Since many of these technologies are still relatively expensive, are perceived to perform poorly when compared to incumbent technologies, and require major infrastructure investment, this focus has reinforced the notion that the transport sector can only make a limited contribution to total carbon dioxide (CO_2) emissions reduction, particularly in the short to medium term. Many policy instruments focus on providing incentives, in particular through economic instruments designed either to affect the prices of energy and carbon or to provide incentives for development and deployment of new low-carbon technologies (Mandell, 2009; Santos et al., 2010).

Car use dominates surface passenger transport, is almost entirely dependent on fossil fuels and reducing it effectively is challenging (Graham-Rowe et al., 2011; Poudenx, 2008). In the UK, total domestic GHG emissions were 782 Million tons of CO_2 equivalent ($MtCO_2e$) in 1990 (DfT, 2011). Domestic transport made up 16% of this total, and cars 9%. While total GHG emissions decreased by 28% between 1990 and 2009, domestic transport and car emissions have stayed roughly constant, increasing their shares to 22% and 13% respectively.

Decarbonization and electrification of the passenger vehicle fleet is a key cornerstone of the UK’s climate change strategy and viewed as necessary to achieve the Government’s legislated 2050 target to cut CO_2 equivalent emissions by 80% from 1990 levels (Ekins et al., 2009; UK Committee on Climate Change, 2009). Some analysts say that, to meet the now legislated 2030 mid-term target of 60%, the UK will have to *“generate 97 per cent of electricity from low carbon sources like nuclear or wind, insulate 3.5 million homes and ensure 60 per cent of new cars run on electricity”* (UK Committee on Climate Change, 2011). While the new car market has visibly shifted towards lower carbon cars particularly in the last 5 - 10 years (Figure 1), just 167 pure electric and 22,148 hybrid vehicles were newly

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[1] GHG emissions are expressed in this paper as carbon dioxide (CO_2) equivalent, CO_2e, based on the 100-year global warming potentials of CO_2, methane (CH_4) and nitrous oxide (N_2O).

registered in 2010 – representing only 1.1% of total UK new car registrations (SMMT, 2011). The SMMT cite *"poor range, high costs and disappointing performance"* (ibid) as the main reasons why drivers are reluctant to make the switch to EVs.

The UK policy focus on vehicle technology and supporting fiscal incentives reflects other global transport modeling exercises that depend upon between 40% to 90% market penetrations of technologies such as plug-in hybrids and full battery electric light duty passenger vehicles between 2030 and 2050 (IEA, 2011; McKinsey & Company, 2009; WBCSD, 2004; WEC, 2007). Despite this focus and the need to meet legislated short and medium targets, there is a gap in understanding the carbon emission reduction effects of individual vehicle tax policies. The evidence we have is mostly *ex-ante* (Bastani et al., 2012; BenDor and Ford, 2006; Greene, 2009; Greene et al., 2005; Haan et al., 2006; Skippon et al., 2012; Spitzley et al., 2005), with some notable attempts of *ex-post* evaluation of fiscal policy instruments on passenger car sales and CO_2 emissions (Ryan et al., 2009), car taxation policy in Ireland (Rogan et al., 2011) and the car registration fee in the Czech Republic (Zimmermannova, 2012). However, with the exception of Spitzley et al (2005) and Bastani et al. (2012), none of these are on a life cycle analysis basis which not only looks at direct (or tailpipe, at source) GHG emissions but also takes into consideration indirect GHG emissions from fuel supply, vehicle production, maintenance and scrappage. Finally, there is also lack of exploring cumulative totals or budgets of GHG emissions over given periods as much of the focus has been on meeting annual targets (e.g. 2020, 2050) (Skippon et al., 2012).

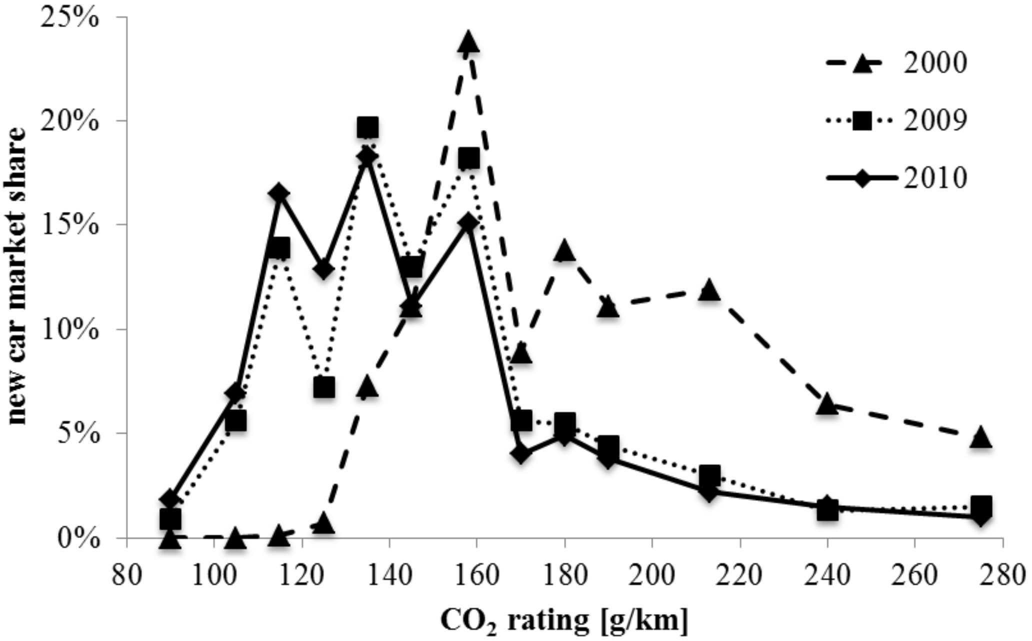

Figure 1: New car market shares by CO_2 rating in the UK, 2000-2010

Source: SMMT (2011)

Total CO_2 from passenger cars is of course not only a function of its efficiency, but also of how much a car is used. Although newer cars emit less CO_2 per kilometer, drivers may use their new cars more and drive further, offsetting (and potentially eliminating) any emissions gain. There are a variety of reasons that could lead to new vehicles being driven more miles than older ones and, therefore, usage needs to be taken into account in the evaluation of taxation schemes, particularly those which accelerate the uptake of new vehicles such as scrappage schemes. Firstly, the classic 'rebound effect' maintains that, given the increase in fuel efficiency of a new car, the marginal cost of driving is lower (Small and Van Dender, 2007). Secondly, newer vehicles are likely to be more comfortable which also reduces the marginal 'costs' of driving. This is borne out in UK travel statistics where the drivers of cars over 10 years old drive on average 10,600km/year and those driving new cars drive around 2,500km/year further (ONS, 2007).

In addition to life cycle impacts and possible impacts on car use with respect to GHG emissions, much analysis of motoring taxation and changes to the car market fails to examine the impact on Government revenue (a notable exception is Rogan et al., 2011). Although not necessarily originally introduced with an environmental purpose, revenue raised from all forms of motoring taxes including fuel taxes and taxes on car ownership comprise by far the most significant environmental taxes in the UK and many other countries (Mirrlees et al., 2011; Ryan et al., 2009). As increasing fuel efficiency and the penetration of alternatively fuelled vehicles begin to reduce taxation revenue, Governments are likely to need to replace that revenue with other forms of taxation. Whether or not this takes the form of further taxes on motoring including electricity use within this sector remains to be seen.

1.2 Aims and objectives

Using the context of light duty passenger vehicles in the UK, this paper first examines the historical evidence and then explores the long term life cycle[2] carbon effects of three fiscal incentives and a number of variants developed within a systematic scenario modeling framework, using real life data and assumptions. By doing so it aims to assess which types and levels of policy ambition of taxation on low carbon passenger vehicles accelerates fuel, technology and purchasing behavioral transitions the fastest with (i) most life cycle GHG emissions savings, (ii) potential revenue neutrality and (iii) no adverse effects on car use. Whereas implications for policy choice, design and timing are discussed, issues of the wider political acceptability and issues of equity are outside the scope of this paper.

Fiscal incentives for passenger vehicles can broadly be split into policies that *primarily* affect vehicle ownership (either upfront or during the lifetime of the vehicle e.g. purchase taxes, feebates, scrappage schemes and vehicle circulation taxes) or vehicle use (e.g. distance based charges, fuel taxation, carbon taxation). In this paper we focus on the former, namely (1) vehicle purchase taxes or 'feebates', (2) graduated vehicle road taxes and (3) vehicle scrappage schemes. Fuel pricing and taxation has been excluded for mainly three reasons. First, the literature on the effects of graded CO_2 vehicle taxes that directly affect the up-front costs as well as future annual payments for ownership of a vehicle is less developed than for fuel pricing/taxation (which are covered well in e.g. Goodwin et al., 2004; Schipper et al., 2011). Second, recent empirical evidence (Boutin et al., 2010; Rogan et al., 2011) suggests that ownership tax differentials and incentives can be successful in

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[2] In this paper we define life cycle energy use and emissions as the sum of *direct* (tank-to-wheel, tailpipe, at source) and *indirect* (well-to-tank or upstream emissions from fuel supply, plus process emissions from vehicle manufacture, maintenance and scrappage) energy use and emissions.

influencing purchasing decisions of alternative fuelled cars, yet the rate and level of success need to be explored further and applied in futures studies exploring the medium to long term effects of such policies. Third, the current UK fuel duty rates for liquid road fuels (gasoline, diesel, biodiesel, bioethanol) are already relatively high at GBP0.58/liter[3], with little room for maneuver in terms of political and public acceptance.

The three types of fiscal incentives are briefly reviewed in the next section before going on to outline the methodology and scenarios used in the modeling. The paper then presents and discusses the main results before concluding with the main implications for policy and practice.

2 WHAT WE KNOW

The main objective of the three fiscal incentives covered here is to send a price signal to private consumers and fleet operators designed to influence purchasing decisions towards a number policy goals, including environmental goals (e.g. engine efficiency, carbon emissions, local air pollution) and economic goals (e.g. vehicle taxation revenues, vehicle ownership levels) (AEA Technology Environment, 2007; de Haan et al., 2009; Newberry, 1995). Depending on how they are designed, incentives that target vehicle ownership can be used to control overall vehicle ownership and size of the vehicle fleet, vehicle engine efficiency and the development of new technology (Jansen and Denis, 1999). The level, structure and phasing of the charge necessary to achieve these goals will depend on the instrument, with budget neutrality an often desired but difficult to achieve secondary objective. In the EU there has been a shift over the last 10 years from basing vehicle taxes on engine power, volume and vehicle mass to fuel economy and CO_2 emissions (Rogan et al., 2011; Ryan et al., 2009). The following sections review the key evidence. For the reasons given above we have excluded fuel taxation from this review. (For recent econometric and modelling studies on fuel pricing and other fiscal incentives see e.g. Goodwin et al., 2004; Ross Morrow et al., 2010; Ryan et al., 2009; Sterner, 2007).

2.1 Vehicle Purchase Taxes and ‘Feebates’

Vehicle purchase tax or, registration tax, is a one-off charge when a vehicle is registered. It is a levy at the point of purchase of a private vehicle, usually payable when a car is sold to its first buyer. These taxes are differentiated by different factors, such as price, engine capacity, power or vehicle weight measures, fuel type, carbon emissions, fuel consumption or a combination of these factors (Anable and Bristow, 2007; TNO, 2006).

A feebate is a combination of a vehicle purchase tax/fee and a rebate/subsidy (Gallagher and Muehlegger, 2011) used to reward buyers of vehicles that are more fuel efficient than the average vehicle in that class and penalize buyers of less fuel efficient vehicles. The set level can correspond to a sales-weighted standard or other value, and can be reduced over time. Some commentators suggest that feebates are more publically acceptable than other fiscal and regulatory instruments because of the reward element (Musti and Kockelman, 2011). While both purchase taxes and feebates can be matched up

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[3] In March 2011, the average price of gasoline was GBP1.33, including GBP0.58 for road fuel duty and GBP0.22 for value added tax (VAT). Thus, 60% of the price of gasoline was tax.

to specific vehicle types (Greene et al., 2005; Johnson, 2007), only feebates can be designed to be revenue neutral (BenDor and Ford, 2006; de Haan et al., 2009; Gallagher and Muehlegger, 2011). However, it can be difficult to ensure budget neutrality as consumer behavior is difficult to predict. For instance, the French experience with the bonus/malus scheme showed that vehicle purchasers reacted more positively to the feebate than expected with the result that the public budget was EUR 500milion in debt in 2010 as a result of the scheme, prompting a readjustment. Nevertheless, preliminary results of the French feebate program show that the average new light duty vehicle CO_2/km went from fourth lowest to the lowest (~133 g CO_2/km in 2009) across the EU since the program started in 2007 (Boutin et al., 2010). Further recent empirical research in the US suggests that not all incentives are equal and feebate programs may be more effective for accelerating the adoption of hybrid vehicle technology than the equivalent fuel-economy based registration due to its transparency at the point of purchase and implied lower discount rate (Gallagher and Muehlegger, 2011).

2.2 Vehicle Excise Duty and Road Tax

Vehicle Excise Duty (VED) also commonly known as vehicle road tax is an annual tax levied on vehicles in order to use public roads. Typically, the amount of charges levied are based on vehicle characteristics such as engine size, weight or power but are increasingly linked to specific environmental characteristics including CO_2 and other pollutant emissions (Harmsen et al., 2003).

In the UK, the CO_2-graded VED scheme first introduced in 2001 was recently reformed with higher band resolution (10-15 gCO_2 between bands, now A to M), slightly higher duties (band M vehicles are charged GBP435, rising with retail price index as of April 2011) as well as the introduction in 2010 of a high first year VED rate for more polluting cars akin to a purchase tax (HM Treasury, 2008; UK House of Commons, 2010). Alternative fuelled cars (i.e. not gasoline or diesel) are charged GBP10 less than their conventional counterparts in the same CO_2 band.[4]

The effectiveness of VED (and similar instruments) is largely influenced by the level of charge necessary to influence consumer behavior (EST, 2007; EST and IEEP, 2004; UK DfT, 2003). Studies on the impact of VED upon vehicle purchasing behavior in the UK have had mixed results. A Government survey examining the potential response to greater differentials between VED bands found 33% of respondents would buy a different vehicle if the difference was GBP60 (at 2009 prices) rising to 55% for a GBP180 differential (UK DfT, 2003). The highest difference offered in the survey was GBP360 at which point 28% would not switch, rising to 40% for those owning larger vehicles. Conversely, only 3% of respondents stated that VED was important in influencing purchase choice whereas the second most frequently mentioned influence was fuel consumption at 26%. In contrast, a survey for the RAC Foundation found that annual costs would have to increase by at least GBP1,200 before consumers would switch to more efficient vehicles (Lane, 2005). However, as the surveys are somewhat dated – performed when graduated VED was first introduced – it is possible that consumer perceptions and preferences have changed.

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[4] Unless noted otherwise all currency figures were converted to 2009 prices.

2.3 Vehicle Scrappage Schemes

Vehicle scrappage schemes are a financial incentive for drivers of older vehicles to prematurely remove their vehicle off the road before the vehicle's lifespan is completed. Vehicle scrappage schemes therefore target older vehicles, which often have lower fuel efficiency and higher carbon emissions than newer vehicles. There are typically two broad categories of scrappage schemes: (1) *Cash-for-Scrappage*, which is a payment offered to consumers for their vehicle regardless of how the consumer replaces the scrapped vehicle, and (2) *Cash-for-Replacement*, which is a payment conditional upon the consumer replacing the scrapped vehicle with a specific type of vehicle, typically, but not necessarily, a new car (CEMT, 1999). A number of schemes were introduced in Europe (Germany, France, Italy, UK) and North America following the global economic downturn in 2008/09 (Foster and Langer, 2011; ITF, 2011). The USA's "Car Allowance Rebate System" (CARS) targeted "gas guzzling" cars and light trucks by offering vouchers worth up to USD4,500 (GBP2,767[5]) for people scrapping vehicles that do fewer than 18 miles per US gallon (or more than 300gCO_2/km for petrol vehicles). The UK's Scrappage Incentive Scheme, on the other hand, was not based explicitly on any efficiency or environmental criteria but provided a GBP1,000 incentive, with matched funding from vehicle manufacturers, for consumers to replace their 10 year old or older vehicle (8 years in the case of vans) with a brand new vehicle. The UK scheme lasted for nearly a year during 2009/10, reportedly having generated nearly 400,000 new car registrations over the period, or about 20% of all new cars registered in the UK (SMMT, 2010).

2.4 Effectiveness to Reduce Carbon Emissions

We briefly review the observed impacts of the above instruments to encourage carbon emissions reduction. First, the impacts of **VED** on carbon emissions reduction are not well understood. In 2006, an environmental excise duty was introduced in Sweden consisting of a base charge of SKR 360 (GBP30) plus a CO_2 charge of SKR 15 (GBP1.3) per gram of CO_2 exceeding 100 grams per kilometer. This charge applies for typical gasoline passenger cars, while for alternative fuelled cars the carbon charge is SKR 10 (GBP0.85) per gCO_2/km. Between 2005 and 2006 the share of lower CO_2 emitting vehicles quadrupled rising from 2.9% to 12.8% (Borup, 2007). By April 2007, this figure increased to 14.3% where the amount of vehicles with emissions less than 120 gCO_2/km was three times higher than in 2006. However, the impact of VED upon consumer behavior is relative given that, despite this rapid uptake of more efficient vehicles, Sweden still has among the highest levels of high CO_2 emitting vehicles in Europe. Nevertheless, at least one commentator has credited the Swedish excise tax as contributing to changing consumer behavior (Borup, 2007).

Second, evidence of the effectiveness for reducing carbon emissions of **vehicle purchase tax** is also mixed. In Sweden, it was estimated that the restructured registration tax would reduce CO_2 emissions by 5% per year over twenty years (COWI, 2002). However, in the shorter term (five years), savings were limited to just over 1% (TNO, 2006). In the Netherlands, the car purchase tax was estimated to reduce 0.6-1 MtCO_2 per year representing 2 to 3% of total transport carbon emissions (Harmsen et al., 2003). However,

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[5] Converted using www.xe.com and assuming mid 2009 currency conversion values.

this estimate was based on a comparison of the average car size in the Netherlands compared to the average size in countries without purchase tax, thus potentially overestimating the effect on car size as there are likely to be other factors that also contribute to lower average car sizes. An econometric modeling study using data from 1995-2004 suggested that registration taxes in place in that period did not have an important impact on the CO_2 emissions intensity of the new passenger car fleet over and above the effects of circulation and fuel taxes (Ryan et al., 2009). In Ireland, on the other hand, the car tax changes in July 2008 from being based on engine size to CO_2 emissions performance were estimated to reduce average specific emissions of new cars by 13% to 145 g/km in the first year of the scheme, saving 5.9 $ktCO_2$ (Rogan et al., 2011). The price signal did however result in a 33% reduction in tax revenue.

Third, the evidence on carbon savings from **scrappage schemes** remains scarce, mainly because the schemes in Europe and the USA had been introduced primarily to stimulate the car market rather than to meet any explicit environmental objectives. That evidence concluded that scrappage incentives can decrease new car CO_2 emissions, but the environmental gains could be much greater if targeted at the retirement of gross emitters still in use and if thresholds for new car fuel economy, fuel consumption and other pollutant emissions are not only set but are also *aligned* (Foster and Langer, 2011; ITF, 2011). For instance, whilst the French scheme imposed a CO_2 limit for new cars, it led to a very high share of diesel cars with associated consequences for PM_{10} and NO_X emissions (ibid.). Thus, any assessment of the potential life cycle impact of scrappage schemes needs to account of a variety of complex direct and indirect impacts on the car market (Kavalec and Setiawan, 1997). Key factors that would need to be considered are: how much earlier the vehicle was retired because of the program; how many kilometers the vehicle would have been driven if it was not retired; the emissions levels of the retired vehicle; and the emission levels, remaining life and vehicle miles travelled by the replacement vehicle, if there is one (Dill, 2004). Moreover, the additional energy and emissions generated from the manufacture of replacement vehicles and the dismantling and recycling of the scrapped vehicles have not typically been accounted for (CEMT, 1999; Spitzley et al., 2005). Therefore, there has been considerable difficulty in assessing the life cycle carbon savings from a scrappage policy but use of the specific modeling approaches used in this study aim to address some of this complexity.

3 METHODOLOGY

The approach taken for this work involves a systematic comparison of quantified policy scenarios of fiscal incentives for cars up to 2050. The modeling of these policy scenarios involved (1) framing and development of a reference and nine alternative policy scenarios of fiscal incentives for cars; (2) detailed sectorial modeling using the previously developed and published UK Transport Carbon Model (UKTCM) in order to simulate the impacts of the developed fiscal policy scenarios on car ownership, car technology choice, fuel/energy use and life cycle carbon emissions and UK Government tax revenue; and (3) sensitivity analysis of key modeling parameters, adding five further policy scenarios.

3.1 UK Transport Carbon Model: summary and updates since Brand et al. (2012)

The UKTCM is a highly disaggregated, bottom-up model of transport energy use and life cycle carbon emissions in the UK. The UKTCM provides annual projections of transport supply and demand, for all passenger and freight modes of transport, and calculates the corresponding energy use, life cycle emissions and environmental impacts year-by-year up to 2050. It takes a holistic view of the transport system, built around a set of exogenous scenarios of socio-economic and political developments. The model is technology rich and, in its current version, provides projections of how different technologies evolve over time for more than 600 vehicle technology categories[6], including a wide range of alternative-fuelled vehicles such as more efficient gasoline cars, hybrid electric cars, plug-in hybrid vans and battery electric buses. The UKTCM is specifically designed to develop future scenarios to explore the full range and potential of not only technological, but fiscal, regulatory and behavioral change transport policy interventions. An example is the recent *Energy2050* work of the UK Energy Research Centre (UKERC) where UKTCM played a key role in developing the ‘Lifestyle’ scenarios (Anable et al., 2011; Anable et al., 2012). An introduction to the model has been published in Brand et al. (2012); further details can be obtained from the Reference Guide (Brand, 2010a) and User Guide (Brand, 2010b).

Within the UKTCM modeling framework, changing car purchase and ownership costs essentially affects three areas of modeling: (1) the household car ownership model, (2) the car choice model (built around a discrete choice model that includes purchase price and operating costs as choice attributes)[7] and (3) the demand model (built around an elastic demand model with average transport costs as a key feedback parameter between demand and supply). Building on an extensive literature on modelling private consumer energy investments in discrete choice models (Brownstone et al., 2000; Ewing and Sarigollu, 1998; Golob et al., 1997; Horne et al., 2005; Train, 1985), a mid range discount rate of 30% is applied to the private car market and is used to represent investment behaviour and mimic non-cost barriers including lack of information.[8]

For the analysis presented in this paper the UKTCM has been developed, updated and recalibrated from version 1 (Brand, 2010a; Brand et al., 2012) to the current version 2 (V2). The main developmental change was the reclassification and extension of 59 (out of 604) vehicle technologies; UKTCM V2 now includes higher resolution and vintaging of small and medium sized battery electric vehicle (BEV) cars, mini and urban BEV buses, BEV vans and BEV medium trucks. The modeling databases were updated to the latest historic data

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[6] A UKTCM ‘vehicle technology’ is defined as a typical representative of a combination of transport type (passenger or freight), vehicle type (e.g. motorcycle, car, HGV, train), vehicle size (e.g. small car, van, heavy truck, intercity rail), fuel type (e.g. gasoline, diesel, E85, electricity), ‘vintage’ (e.g. ICV Euro IV 2005-09, ICV “Euro VIII” 2020-24, fuel cell EV Standard 3) and hybridisation (ICV, HEV, PHEV). ‘Vintaging’ is used to simulate changes in performance, efficiencies, preferences, costs and discount rates over time.

[7] Building on an extensive literature on actual private consumer energy investments (Train, 1985; Horne et al., 2005; Ewing and Sarigollu, 2000; Bunch et al., 1993), a mid range discount rate of 30% is applied to the private car market and is used to represent investment behaviour and mimic non-cost barriers including lack of information. Note fleet and company cars attract a lower, commercial threshold for capital investments in shape of a 10% discount rate, which is still substantially higher than the standard social discount rate for the UK of 3.5%.

[8] Fleet and company cars attract a lower, commercial threshold for capital investments in shape of a 10% discount rate, which is still substantially higher than the standard social discount rate for the UK of 3.5%.

sources and projections into the future of key modeling inputs, including economic, demographic, transport demand, energy and vehicle technology data, which are summarized in the next Section. UKTCM V2 has been calibrated to UK national statistics for the year 2008 (DfT, 2010).

3.2 The Policy Scenarios

3.2.1 Overview

The core element of the analysis investigated three fiscal policies: (a) purchase taxes and feebates, (b) scrappage rebates and (c) vehicle excise duties (road taxes). For each policy three purely subjective *'policy ambitions'* were explored, ranging from *'low'* (more likely, politically feasible) to *'high'* (less likely, politically not feasible in current climate, but potentially an option if a natural disaster happened /social norms changed significantly). Thus the core analysis involved nine scenarios, as shown in Table 1. To explore the inherent unpredictability in policy making and response during the lifetime of a policy (Bastani et al., 2012), five scenario variants were modeled as part of the sensitivity analysis of key modeling parameters. Electricity as a road transport fuel is currently not taxed in the UK, so to simulate a level playing field with liquid fossil fuel duties two of the sensitivity variants included the gradual phasing in of a GBP0.06/kWh fuel duty between 2021 and 2030.

Table 1: Overview of policy scenarios

	Policy ambition		
Policies	**'Low'**	**'Medium'**	**'High'**
Purchase tax/ feebate	**CPT1** – simple tax of GBP2,000 for new cars with CO_2 >225g/km, tightening every 5 years by one CO_2 band	**CPT2** – feebate graded by fuel type and CO_2, tightening over time: (a) CO_2-graded tax up to GBP4,000 (>200g/km) (b) rebate up to GBP2,000 (<100g/km) (c) 50% tax discount for alternative fuels	**CPT3** – feebate graded by fuel type and CO_2, tightening over time: (a) CO_2-graded tax up to GBP8,000 (>200g/km) (b) rebate up to GBP4,000 (<100g/km) (c) 50% tax discount for alternative fuels
	***CPT1a**: variant with tighter limit of CO_2 >175g/km*	***CPT2a**:higher top rebate of GBP4,000* ***CPT2b**: higher top rebate of GBP3,000; GBP0.06/kWh electric fuel duty*	***CPT3a**: GBP0.06/kWh electric fuel duty*
Vehicle excise duty/ road tax	**VED1** – road tax graded by fuel type, CO_2 rating and year of first registration (first year tax is higher)	**VED2** – as VED1 but tightening of CO_2 limits over time	**VED3** – as VED2 but with double duty rates
Scrappage rebate	**SCR1**: simple, threshold-based rebate of GBP2,000, 2009-2010 only (SMMT, 2010)	**SCR2**: simple, threshold-based rebate of GBP2,000, 2011-2050, tightening by CO_2 limits over time	**SCR3**: rebate of up to GBP2,000 graded by CO_2, 2011-2050, tightening by CO_2 limits over time
		***SCR2a**: variant assuming lower expected car life*	

Note: normal typeface denotes core policy scenario; italic typeface denotes variant / sensitivity scenario

3.2.2 Reference scenario (REF)

To assess the effects of changes in policy against some reference situation, a 'reference scenario' for the outlook period up to 2050 was required. This scenario broadly depicts a projection of transport activity, energy use and emissions as if there were no changes to transport (and fiscal) policy beyond March 2010. It was modeled using UKTCM based on exogenous assumptions and projections of socio-demographic, economic, technological and (firm and committed) policy developments. While it included the relatively complex (fuel type and CO_2 graded) VED scheme as of 2009/2010 (UK House of Commons, 2010), it did not include any scrappage rebates or purchase taxes/feebates.

While the assumptions and data sources given in Brand et al. (2012) and Brand (2010a) served as a starting point for this scenario, a number of key data inputs were updated for this work. Economic growth up to 2011 were based on UK government figures, including the recent recession (HM Treasury, 2010). Future GDP growth were assumed to average 2.25% up to 2050 – in line with the historic 50-year average for the UK. Operating the UKTCM in 'simulation mode', transport demand projections were *exogenously* aligned to the most recent government projections. For road transport, this was based on the 'central' 2009 Road Transport Forecasts (UK DfT, 2010) to 2035 and extrapolated to 2050. Reference energy resource price projections were updated to June 2010 UK Government forecasts (UK DECC, 2010a, b), with the 'central prices' forecast projecting the real term oil price to average USD72 per barrel in 2010, then rising gradually to USD82 per barrel in 2020 and increasing further to USD92 per barrel in 2030. Our reference scenario then extrapolated to 2050 where crude oil was forecast to cost USD113 per barrel.[9] Electricity prices for private consumers were supply costs at the meter and included resource costs (as projected in UK DECC, 2010a, b), duty (currently zero and projected to stay zero for the Reference case) and value added tax (VAT, currently 20%). Vehicle excise and other fuel duties of all vehicle types were assumed to remain constant at pre-April 2010 levels. Following an approach commonly used in technology futures and modeling studies (European Commission, 2005; Fulton et al., 2009; Strachan and Kannan, 2008; Strachan et al., 2008; UK Energy Research Centre, 2009; WEC, 2007), pre-tax vehicle purchase costs were kept constant over time for established technologies and gradually decreased for advanced and future technologies, thus *exogenously* simulating improvements in production costs, economies of scale and market push by manufacturers.[10] For example, average purchase price for BEV cars were assumed to decrease 2% pa from 1996 to 2020, then 1% until 2050. The Reference scenario further assumed gradual improvements in specific fuel consumption and tailpipe CO_2 emissions per distance travelled. The rates of improvement varied by vehicle type, size and propulsion technology and, for future years, were based on technological innovation driven

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[9] These 'official' oil price projections by UK DECC are low when compared to March 2011 prices of about USD110. However, they serve as a reference against which alternative futures should be compared with, in particular in the light of accelerating depletion of oil resources and rapidly evolving policy ambitions (e.g. the UK's Low Carbon Transition Plan, predicting that renewables generate the majority of electricity by 2020). Alternative scenarios could be run based simply on different resource price projections.

[10] The assumption that alternative technologies improve (cost, energy and environmental performance, consumer preferences) at a faster rate over time is in line with other technology futures and modelling studies and applies equally to all scenarios modelled here, not just the reference scenario.

entirely by market competition, not on policy or regulatory push.[11] For example, while the fuel consumption improvement rates for new conventional and hybrid electric (HEV) cars are assumed to be around 0.5% p.a. – a lower rate than the average rate of 1.3% p.a. observed for new cars between 2000 and 2007 (SMMT, 2008) – the rates are higher for BEV, PHEV and FCV (2% pa until 2020, then 1% until 2035, then 0.5% until 2050). The preference and performance attributes used in the vehicle technology choice model (see Brand, 2010a for details) were kept at relatively low values that gradually increase, simulating (a) limited deployment of the charging infrastructure (e.g. only in future 'low carbon cities'), (b) relatively limited market availability of (PH)EV cars and (c) consumer preference for 'conventional' over 'new/unknown' technology. Finally, it was assumed that the carbon content of (road transport) electricity does not vary between scenarios and is still around 400gCO_2/kWh in 2030 (as per Government projections) and out to 2050.

3.2.3 Car purchase tax / feebate

Three alternative car purchase tax/feebate scenarios were modeled. First, 'low' policy ambition was simulated in a car purchase tax with simple grading by CO_2 emissions (**CPT1**), assuming the once proposed (2007/8) but then scrapped level of GBP2,000 for cars emitting more than 225gCO_2/km (car tax band[12] L or M) was put into action between 2011 and 2014. This CO_2 limit was then tightened every five years by one car tax (VED) band, down to a lower limit of 130gCO_2/km from 2045. Alternative fuelled cars running on hydrogen (gaseous, GH_2 and liquid, LH_2), electricity, full biodiesel (B100) and bioethanol blends (E85) carry a 50% *reduction* of any purchase tax as they were assumed to save *net* CO_2 emissions when compared to their conventional counterparts. Secondly, 'medium' policy ambition was modeled as a feebate scheme, graded by CO_2 emissions and tightened over time (**CPT2**). From 2011 until 2014, this involved a GBP4,000 *fee* for cars emitting more than 200gCO_2/km, GBP2,000 for cars emitting more than 175gCO_2/km (and less than 200), GBP1,000 for cars emitting more than 150gCO_2/km (but less than 175), *no* purchase fee for cars emitting between 140 and 150gCO_2/km, a GBP500 *rebate* for cars emitting between 120 and 140gCO_2/km, GBP1,000 rebate for cars emitting between 100 and 120gCO_2/km, and a GBP2,000 rebate for cars emitting less than 100gCO_2/km (Figure 2). The CO_2 limits were tightened every five years by one tax band so that from 2045 the top fee is for cars emitting more than 120gCO_2/km. Biofuel cars (B100, E85) carry a 50% reduction of any fee occurred, but rebates stay at 100%. Hydrogen, BEV and PHEV cars attract the maximum rebate of GBP2,000. Thirdly, 'high' policy ambition in **CPT3** was simulated by simply doubling the fees/rebates of CPT2, i.e. fees of up to GBP8,000 and rebates of up to GBP4,000 per car.

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[11] This implies that the EU mandatory agreement on new car CO_2 emissions would not be met. However, separating innovation by competition and innovation by regulation/policy push is slightly arbitrary here as the effects are never easy to untangle. We merely assume that half of the recent improvement came from market competition and the other half from policy (mainly fiscal) and regulation (mainly VA).

[12] These bands are based on the bands 'A' to 'M' used for VED taxation in the UK.

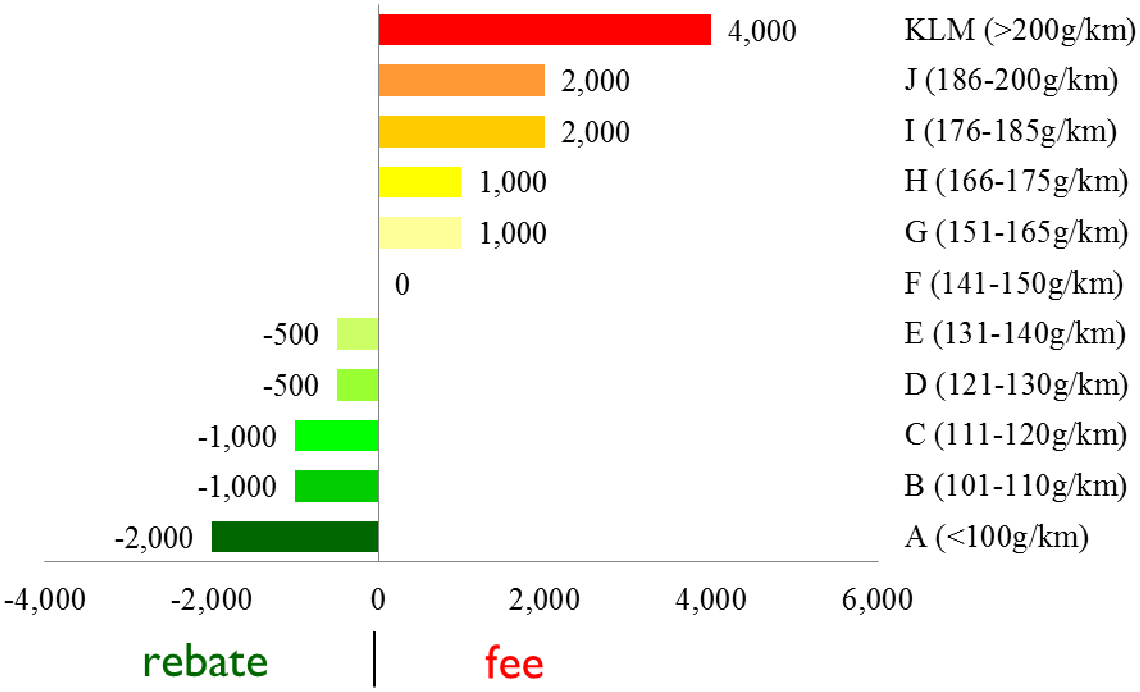

Figure 2: Fees and rebates (in GBP) of the 'medium' policy ambition feebate scheme (CPT2), for conventional fossil fuelled cars between 2011 and 2014

3.2.4 Road tax / vehicle excise duty

The relatively complex scheme that has been in force in Britain since April 2010 serves as the 'low' ambition scenario (**VED1**), involving (a) simple rates for cars registered before 1 March 2001 based on engine size and (b) graded rates for cars registered on or after 1 March 2001 based on fuel type and CO_2 emissions (split into 13 bands, from GBP0 for cars <=100gCO_2/km to GBP435 for >255gCO_2/km; alternative fuelled cars get GBP10 discount). In addition, higher grading was applied *for the first year only* for cars registered on or after 1 April 2010 based on fuel type and CO_2 emissions (higher first year rates for CO_2 > 165gCO_2/km, up to GBP950 for CO_2>255g/km). While the VED1 scenario assumed the limits are *not* tightened over time, scenario **VED2** was based on VED1 but now with *decreasing CO_2 limits* for every 5 years. Finally, **VED3** was set up as VED2 but with *double* duty rates (Figure 3).

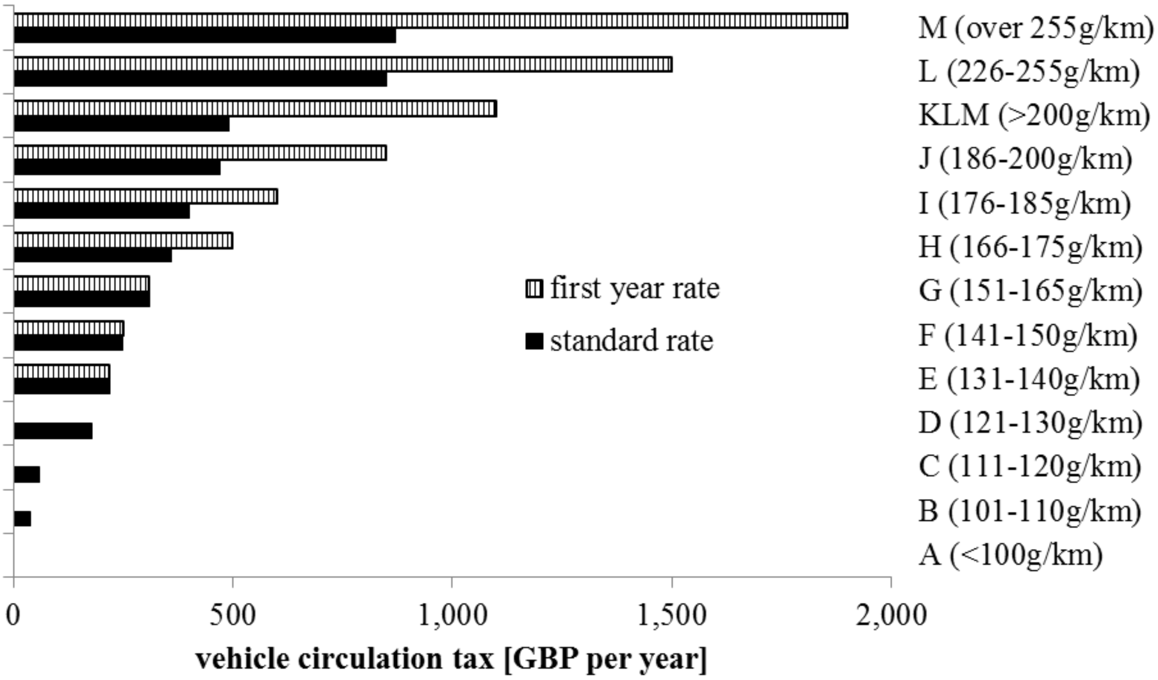

Figure 3: Tax rates assumed for the 'high' policy ambition circulation tax scheme (VED3)

3.2.5 Scrappage rebate

First, 'low' policy ambition on scrappage was tested in scheme 1 (**SCR1**), which simulates the recent UK Government scheme implemented for a period of 10 months during 2009-10. This involved a GBP2,000 cash incentive to new car buyers for scrapping cars older than 9 years[13] with no explicit environmental requirements for the new vehicle purchased. Since the scheme was short-lived we assumed that the average car lifetime would not change as a result. The modeling results allowed for validation against what actually happened. Second, 'medium' policy ambition (**SCR2**) was explored in a simple rebate of GBP2,000 for buying a new low carbon car emitting less than 150gCO_2/km between 2011 and 2014, with the threshold decreasing by one CO_2 emissions band every five years so that from 2045 only cars emitting less than 80gCO_2/km attracted the rebate. Thirdly, 'high' policy ambition (**SCR3**) was modeled as a CO_2-graded rebate of up to GBP2,000 for buying a new low carbon car. The top rebate between 2011 and 2014 was for buying a new car emitting less than 100gCO_2/km, GBP1,000 for cars emitting between 100 and 130 grams, GBP500 for cars emitting between 130 and 165 grams, and no rebate for cars emitting more than 165 grams. The thresholds decreased by one CO_2 emissions band every five years so that from 2045 only cars emitting less than 30gCO_2/km (i.e. mainly for BEV, PHEV and hydrogen FCV) attracted the rebate.

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[13] To put this into context, the number of cars older than 9 years in 2009 was about 6.4 million (or 23% of all cars).

3.3 Sensitivity analysis

The five sensitivity runs included variations of CO_2 emissions limits, expected lifetime of cars and the phasing in of a road fuel duty on electricity. First, scenario **CPT1a** was a variant of CPT1 assuming lower CO_2 emissions limits starting at 175gCO_2/km between 2011 and 2014, then tightening every five years by one car tax band to a lower limit of 100gCO_2 from 2045. Again, hydrogen, BEV, PHEV, B100 and E85 cars get a 50% reduction of the tax. Second, higher top rebates of GBP3,000 and GBP4,000 are simulated in the feebate variants **CPT2b** and **CPT2a** respectively. Third, variants **CPT2b** and **CPT3a** also included the gradual and linear phasing in from 2021 to 2030 of a GBP0.06/kWh[14] duty on road electricity – an obvious choice to test as the UK Government would be expected to introduce such a duty on a shift to road electricity as a main transport fuel. Finally, a longer running scrappage incentive scheme such as SCR2 could potentially result in an average expected lifetime of a car around the cut-off point (10 years) – two years lower than the 2008 figure of 12 years (DfT, 2009). Therefore, we tested a variant of SCR2, **SCR2a**, that assumed a gradual and linear lowering of the average expected car lifetime from 12 to 10 years. As a result, the average age of cars decreased to about 5.3 years (from 6.2 years in 2008).

4 SCENARIO MODELLING RESULTS

4.1 Accelerating low carbon technology uptake

The car purchase tax/feebate policies resulted in fewer cars being bought overall, up to 6% less than baseline for CPT3. This is mainly a result of the higher *average* car purchase price that has a direct effect on household car ownership (see Brand, 2010a for methods). As expected, the scrappage rebate policies had the reverse effect of *increased* car ownership, in particular when accounting for reduced vehicle lifetimes (SCR2a) which result in 18% higher new car purchases than in REF (Figure 4). The main effect of the low ambition scrappage rebate scheme (SCR1) was a temporary increase in car purchasing of about 500,000 cars, followed by a drop of roughly the same magnitude and length. This is in line with observed registration figures during the UK Scrappage Incentive Scheme (SMMT, 2010) which SCR1 is modeled on. In contrast, the vehicle excise policies had little effect on *total* car ownership.

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[14] GBP0.06/kWh is equivalent in energy terms to GBP0.54/litre of gasoline, or GBP0.60/litre of diesel.

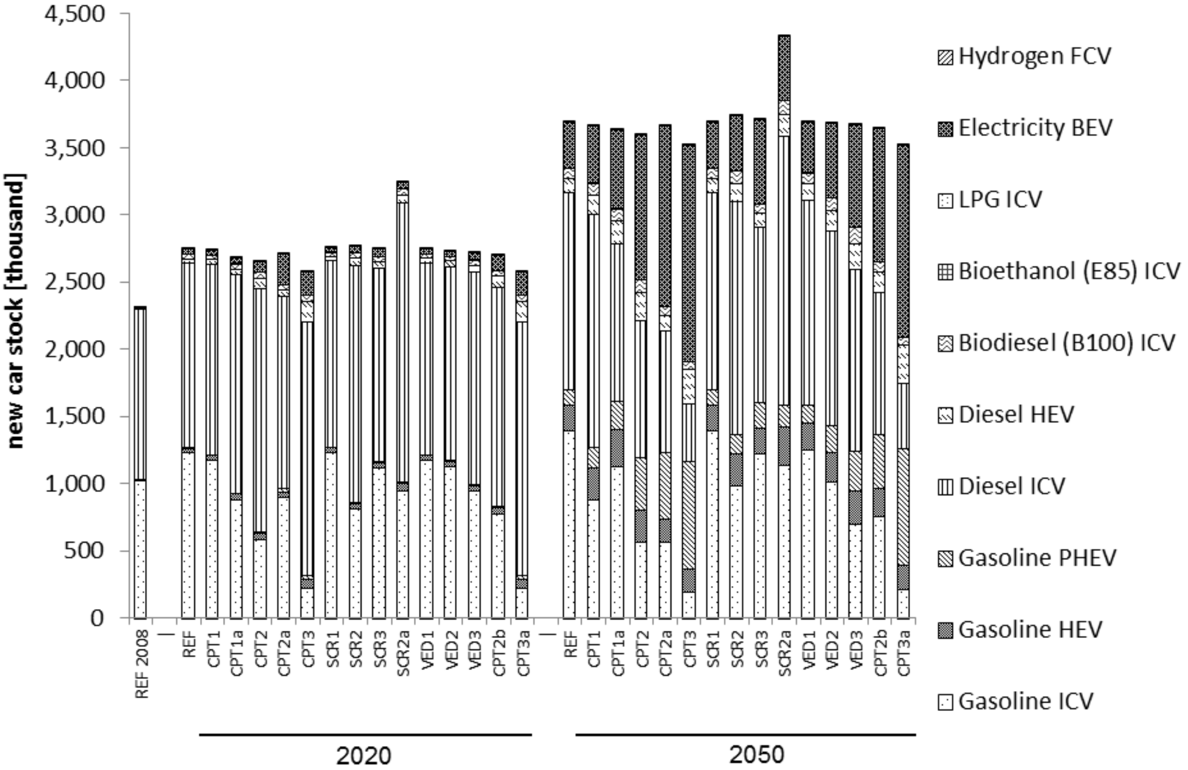

Figure 4: Scenario comparison of the number of new cars by fuel and propulsion technology (2008, 2020 and 2050)

In terms of the technology make-up of the new car fleet, the feebate (CPT2, CPT3) and ‘high’ VED schemes had the biggest impact on accelerating low carbon technology uptake (Figure 4). By 2020, diesel was modeled to overtake gasoline as the main choice of fuel for new cars, and between 1% (REF, CPT1, SCR1, VED1) and 8% (CPT3) of new cars would be plugged-in (BEV, PHEV). While in the Reference case plugged-in cars made up only 6% and 13% of new cars in 2030 and 2050 respectively, their share of new car stock increased to up to 33% (CPT3) in 2030 and 69% (CPT3) in 2050. By comparing the feebate schemes with and without duty on electric road fuel it emerged that the additional duty reduced the acceleration for BEV but conversely increased it for PHEV, with plugged-in cars making up 65% in 2050 with an electric fuel duty (CPT3a). In contrast, whereas the road tax (VED) policies achieved up to 29% penetration of plugged-in cars by 2050, the scrappage schemes had only a moderate effect on technology uptake, mainly increasing the share of diesel and BEV cars in the mix.

The modeled evolution of new car market shares by CO_2 band for variant b of the ‘medium’ ambition feebate policy is shown in Figure 5. The general trend over time (from bottom to top) suggests a marked shift towards lower carbon cars, with 7% (2020), 21% (2030) and 42% (2050) of new cars rated as below $80gCO_2/km$. It is worth keeping in mind that this shift towards more low carbon cars also happened for the REF case, although at a much slower pace with 2% (2020), 8% (2030) and 15% (2050) of new cars below $80gCO_2/km$. Further results on vehicle fleet evolution can be viewed in the supplementary material.

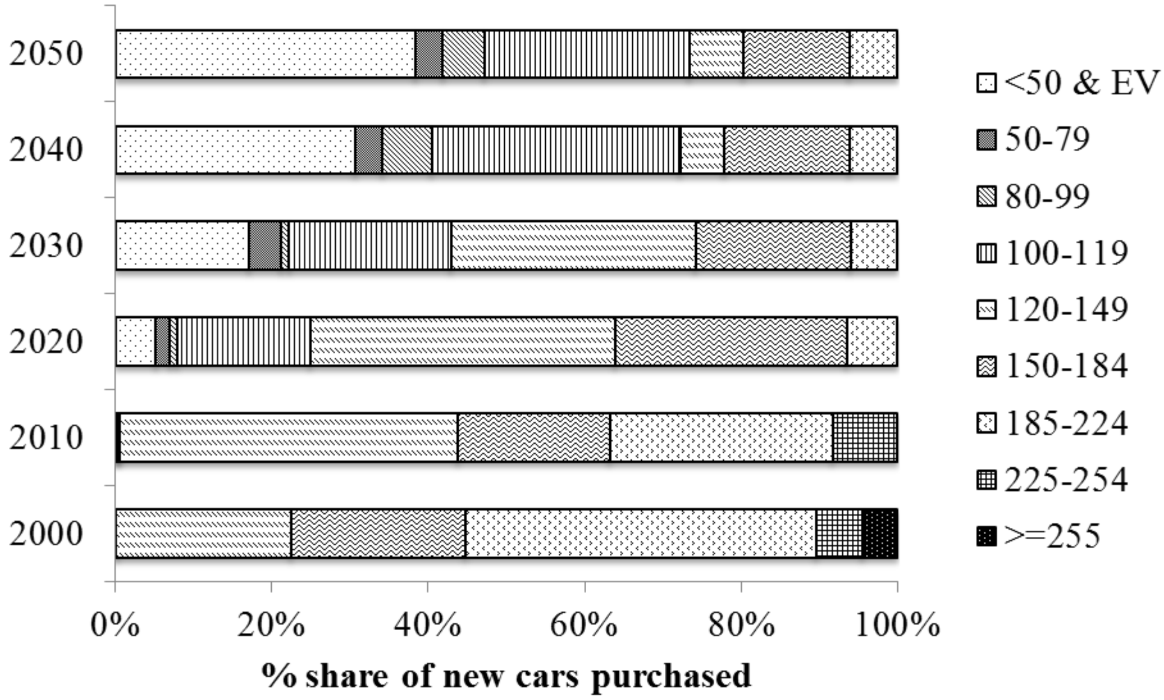

Figure 5: Share of new cars over time by CO_2 band for the 'medium' ambition feebate, variant 'b' (CPT2b)

4.2 Size and rate of emissions savings

In the reference case (REF) *direct* emissions of CO_2 from cars fell from the 2008 level of 72 $MtCO_2$ to 68 $MtCO_2$ (2020) and 61 $MtCO_2$ (2050), with conventional ICV cars contributing 58 $MtCO_2$ and AFV cars 3 $MtCO_2$ in 2050.[15] While the post-2008 economic downturn and rising fuel costs are major factors underlying the short term fall, the longer-term decrease is largely the result of improvements in fuel efficiency and emissions performance of new cars penetrating the fleet (Section 4.1) and some fuel switching to (plug-in) electric cars (ditto), offsetting the overall growth in the demand for car travel (Section 4.3). The REF results can be viewed in more detail in the supplementary material.

When compared to this reference projection, the modeled policy scenarios showed various levels of success in reducing *direct* car CO_2 emissions. As shown in Figure 6, the 'high' policy ambition feebate (CPT3) reduced *direct* emissions fastest and by the highest amounts, saving 10% (2020), 21% (2030) and 49% (2050) of direct car CO_2 emissions. The 'medium' ambition feebates (CPT2/2a/2b) and 'high' road tax scheme (VED3) achieved about half the direct CO_2 emissions savings when compared to CPT3. Interestingly, adding the electric fuel duty in variants CPT2b and CPT3a reduced the savings by only 3-5% in 2050, as relatively *fewer* BEV but *more* HEV and PHEV were purchased.

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[15] Changes in carbon emissions are the result of a number of interrelated factors, including the penetration of lower emission cars into the vehicle fleet, changes in demand for cars and other modes, changes in car total ownership (e.g. a decrease in total ownership means lower indirect carbon emissions from manufacture, maintenance and scrappage) and changes in upstream fuel emissions. For further details on how this is done in UKTCM see Brand (2010a/b) and Brand et al. (2012).

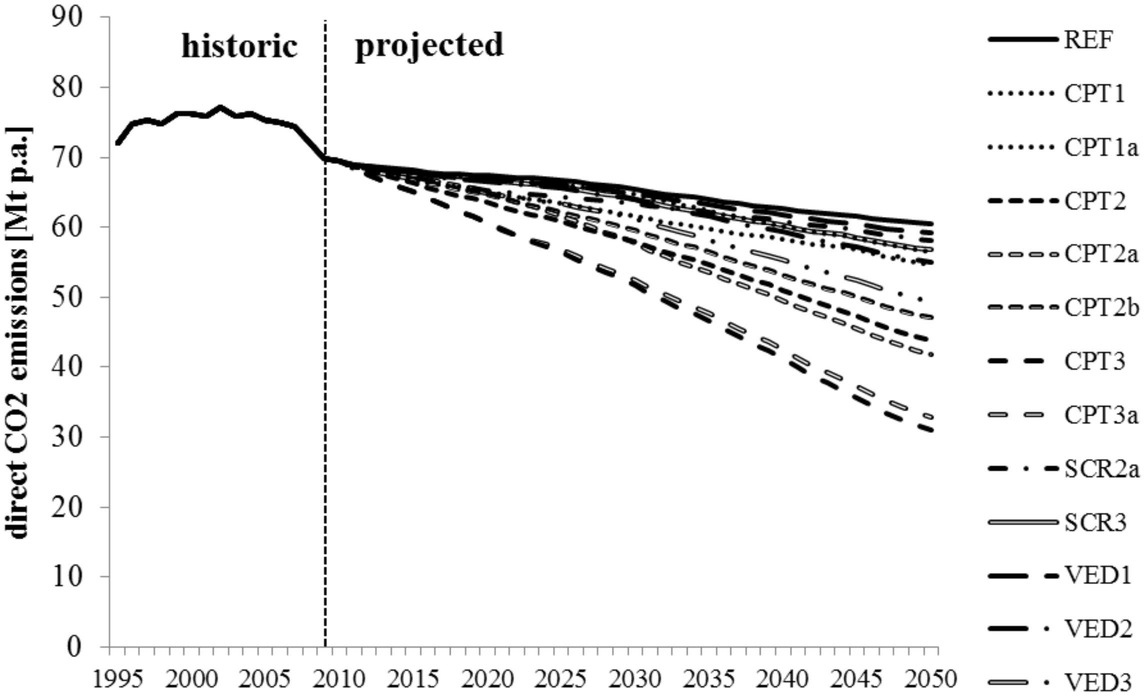

Figure 6: Direct emissions of CO_2 from cars for a selection of scenarios against the reference case

In contrast to the general trend of a decline in *direct* emissions, *total life cycle* GHG emissions in the REF case stayed roughly constant at the 2010 level of 102 $MtCO_2e$ (Figure 7). This can be explained by a gradual increase in *indirect* GHG emissions from growing demand for electricity as a transport fuel as well as steadily increasing car ownership levels (with higher indirect emissions). The more ambitious road tax (VED) and purchase tax/feebate schemes showed the highest overall *reduction* and *steepest decline* over the outlook period. By 2020, life cycle GHG emissions were 2.8% (VED3), 2.9% (CPT2b) and 7.7% (CPT3) below baseline (REF), increasing to 10.0% (VED3), 10.1% (CPT2b) and 20.2% (CPT3) by 2050. Again, adding the electric fuel duty in variant CPT3a reduced the savings only marginally in 2050. Interestingly, the road tax (VED) regimes reduce emissions at a slower rate up to 2030, with similar reduction rates from about 2030. Modeling of the recent scrappage scheme (SCR1, not shown) showed a temporary *increase* of emissions in 2009, followed by a drop in 2010 and 2011, mainly due to increasing then decreasing emissions for vehicle manufacture and scrappage. Over the three years, the scheme increased net GHG emissions by 1.2 $MtCO_2e$. Similarly, the long term scrappage scheme with lower expected car lifetimes (SCR2a) resulted in *higher than baseline* emissions, suggesting that the higher indirect emissions from increased vehicle manufacture and scrappage are not offset by the take up of lower carbon cars shown in Figure 4 above.

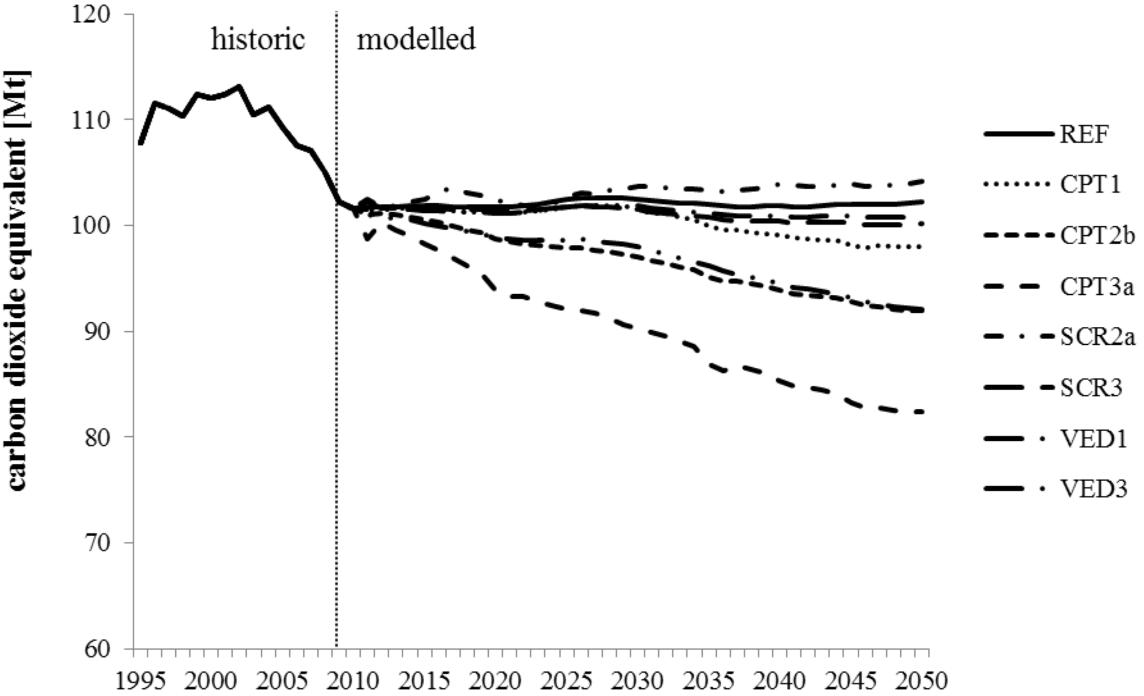

Figure 7: Life cycle greenhouse gas emissions (as CO_2e) from cars for a selection of scenarios against the reference case

Given the analysis so far it comes as no surprise that the purchase tax/feebate schemes *cumulatively* saved the most life cycle GHG emissions, as shown in Figure 8. The ‘high’ feebate scheme (CPT3) cumulatively saved 42 $MtCO_2e$ over the short-term period 2010 to 2020, that is, 2.2% when compared to baseline cumulative emissions of 1,921 $MtCO_2e$. This can be explained by a combination of lower overall car ownership and increased consumer preference for diesel ICEs and HEVs. In the medium term (up to 2030), the four most promising policy options were the car purchase tax with tighter limits (CPT1a), the car purchase feebates (CPT2, CPT3/3a) and the highly graded VED scheme (VED3), saving between 55 $MtCO_2e$ (VED3) and 148 $MtCO_2e$ (CPT3) by 2030. In the long term (up to 2050), up-front pricing incentives saved between 155 $MtCO_2e$ (CPT1a) and 493 $MtCO_2e$ (CPT3) in total. In contrast, while the ‘low’ and ‘medium’ excise duty schemes only have any sizeable effect in the long term, the scrappage schemes only show very small reductions (SCR2, SCR3) or even an increase (SCR2a) in the region of 1% of total cumulative GHG emissions.

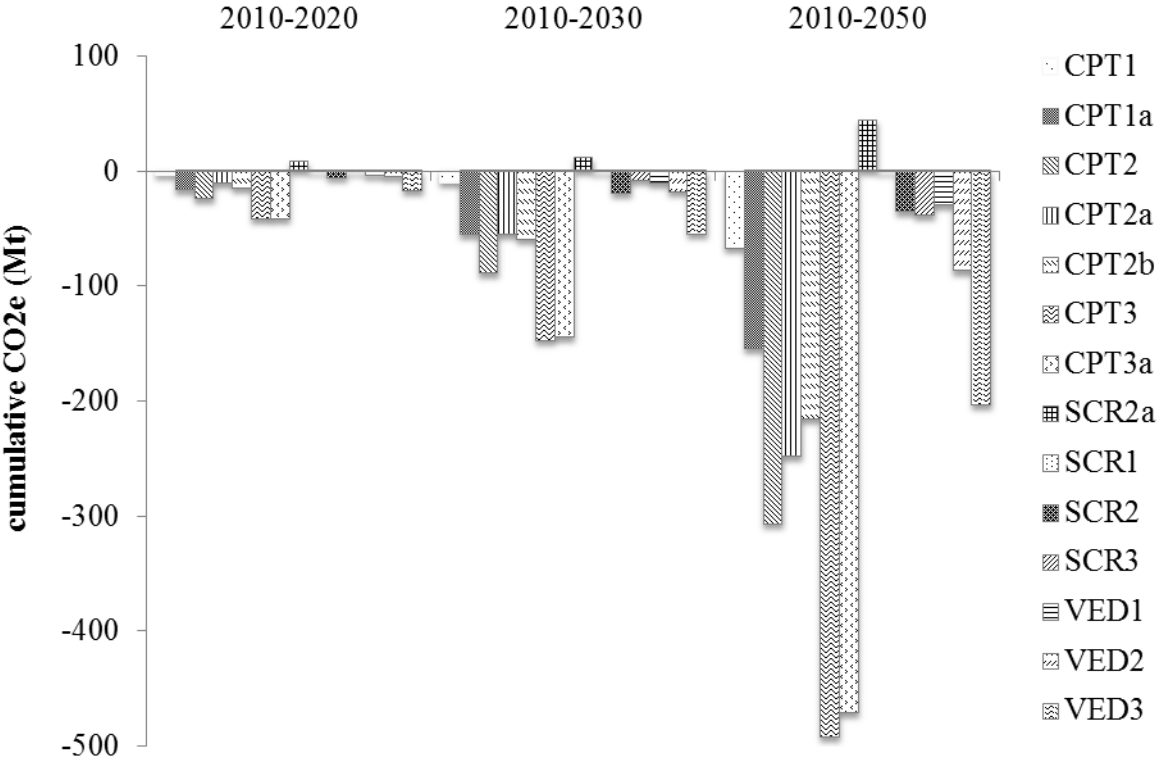

Figure 8: Life cycle GHG emissions, cumulative savings over baseline (REF) in $MtCO_2e$

4.3 Effects on car use

When compared to the Reference case, which projected car use (vehicle-kilometres, or VKM) to increase by 27% between 2010 and 2050, the policies modeled here altered this trend little, with car use varying between -3% to +3% over baseline projections (Figure 9). The 'medium' ambition car scrappage schemes (SCR2/2a) showed the unwanted effect of increasing car use by up to 3% (2050) over the Reference case – a direct effect of lower average car transport costs[16]. In contrast, the more ambitious excise duty regimes were projected to *lower* car use overall due to higher operating costs, with reductions of 1.7% (2030) and 2.5% (2050) for VED3 over the REF baseline.

The message for the purchase tax/feebate schemes was more mixed and depended on the overall balance between fees and rebates. Whereas the car purchase tax policies (CPT1/1a) and 'medium' feebate policy (CPT2) suppressed car use by up to 1.8% by 2050, the 'high' feebates (CPT3/3a) first reduced car traffic but then showed an increase in the medium to longer term, up to 2.5% by 2050. This can be explained by the fall in average new car transport costs from about 2035, as the number of new cars attracting the rebate then outweighed the ones with fees. In reality, the balance between fees and rebates is likely to be readjusted over time to protect revenues and keep voters happy. Testing this potential readjustment by assuming a higher top rebate of GBP3,000, variant CPT2b showed only

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[16] Demand for travel is partly a function of generalised transport costs which includes costs of vehicle ownership and use. Generally, a decrease in car transport costs increases the demand for car use (and modal shifts from other passenger transport modes to cars). Increases in comfort from new cars is not included in the generalised cost calculation in the model but is included in the car technology choice model.

small (<0.5%) changes in car demand over the modeling period, a result of relatively small changes in average car prices and average transport costs.

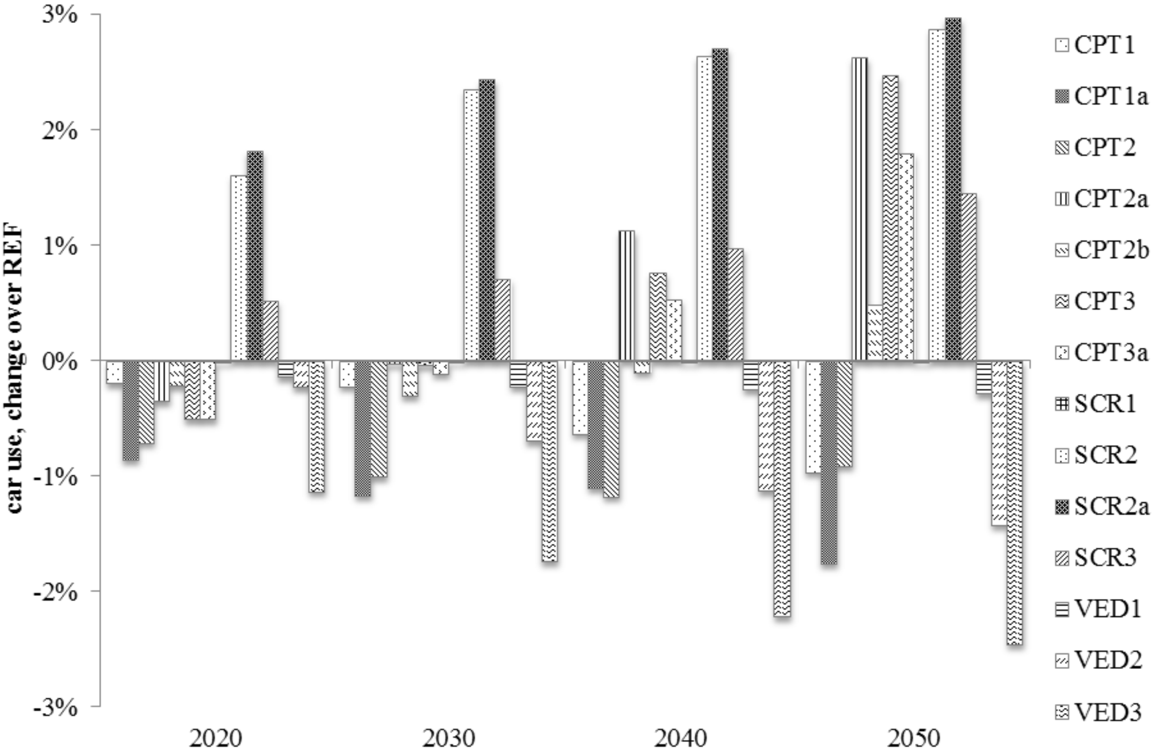

Figure 9: Scenario comparison of car use as percentage change over baseline

4.4 Public finance implications

Over GBP5.1 billion were raised through vehicle excise duty on cars and light vans in 2008/09, and about GBP24.6 billion were raised through road fuel tax in the same year (DfT, 2010). When compared to these considerable revenue streams, the 'low' ambition car purchase tax schemes (CPT1/1a) provided significant and rising vehicle based revenues to the UK Treasury of between GBP0.33 billion in 2020 (CPT1) and GBP4.6 billion in 2050 (CPT1a), which were partly offset by the relatively minor loss in fuel duty revenues of between GBP0.12 billion in 2020 (CPT1) and GBP1.29 billion in 2050 (CPT1a). While the 'medium' feebate with a top rebate of GBP2,000 (CPT2) provided net revenue *increases* for the government of up to GBP2 billion in 2030, the variant with a higher top rebate of GBP4,000 (CPT2a) resulted in net revenue *losses* of about the same amount in 2030, and higher losses of GBP5.4 billion in 2050.

With a top rebate of GBP3,000 and 6 pence/kWh electric duty, CPT2b was essentially revenue neutral – at least in the short and medium term – as illustrated in Figure 10. One of the interesting results of this policy is that new diesel ICV cars were, at first, financially supported by the scheme then penalized in the longer term – reflecting that the tightening of CO_2 limits outpaces the fuel efficiency improvements assumed for diesel ICV technology. This scenario variant further resulted in a 40-year net present value (NPV, at a social discount rate of 3.5%) for vehicle based revenue streams of GBP -1.3 billion – a NPV value that was closest to zero amongst all the policy scenarios. In contrast, the 'high' feebate scheme (CPT3) resulted in lower revenue income and higher subsidies in the longer term as rebates outweigh fees. This imbalance would probably be corrected towards neutrality, similar to the situation in France where changes to the Bonus/Malus program were implemented in order to reduce the scheme's deficit (Diem, 2011).

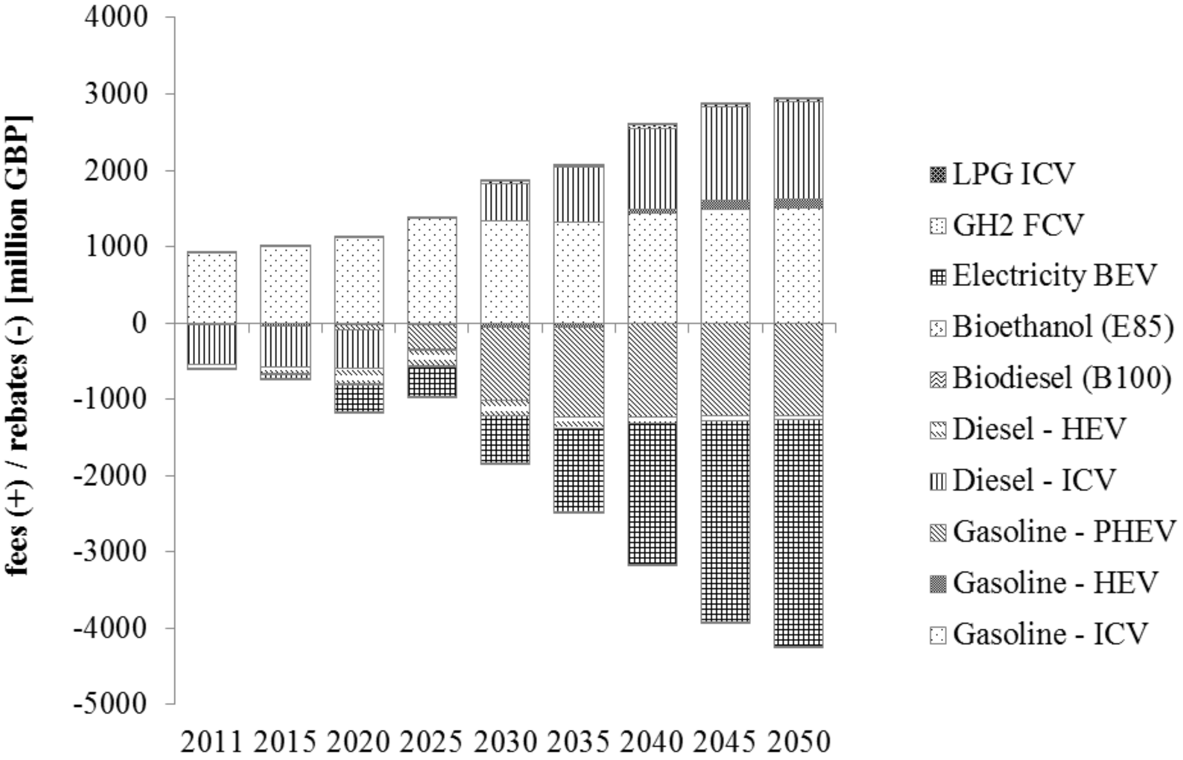

Figure 10: Revenue streams from fees and rebates for the 'medium' ambition car purchase feebate (CPT2b, with GBP3,000 top rebate and GBP0.06/kWh electric fuel duty)

The more ambitious scrappage schemes (SCR2/2a/3) essentially subsidized the car manufacturing industry. The 'high' ambition scrappage rebate scheme (SCR3), for instance, implied subsidies totaling GBP0.13 billion in 2020, rising to GBP0.35 billion in 2050, as well as lost revenue from fuel taxation of GBP0.16 billion in 2020 rising to GBP0.77 billion in 2050. This can be explained by moderate fuel switching against the background of small increases in car use.

On pure revenue generating terms the VED schemes were the clear winners, in particular the VED schemes that tighten CO_2 limits over time (VED2/3). These were only partially offset by the loss of fuel duty revenues so that net revenues totaled between GBP3.8 billion (VED2) and GBP9.9 billion (VED3) in 2030, with even higher revenues of GBP9.8 billion (VED2) and GBP16.3 billion (VED3) in 2050. Even the recently amended regime (VED1) provided net increases in revenues of up to GBP1.7 billion in 2050 over the baseline (pre-April 2010) policy – a 7% increase of current road fuel tax revenues.

5 DISCUSSION

The results of a number of relevant UK policy scenarios presented above provide further evidence that policy choice, design and timing can play crucial roles in meeting multiple policy goals (Bunch and Greene, 2010; Peters et al., 2008). Of all the policy types and potential UK policy ambitions modeled for this paper, the more ambitious feebate schemes were faster in accelerating low carbon and plugged-in technology uptake, particularly in the short to medium term. However, since the tax/rebate levels are set at slightly different amounts within policy ambitions, it cannot be judged conclusively whether this is a result of more favourable parameters (as modelled) or whether one type of instrument is more effective than another.

In terms of adoption rates of low carbon vehicles and carbon emissions savings, the results of this study are generally in line with other studies, including the shift to more efficient diesel ICV in the short to medium term as observed in the Irish case (Rogan et al., 2011), the potential adoption rates of PHEV in Austin, Texas (Musti and Kockelman, 2011) and the ineffectiveness of vehicle purchase credits (or rebates) in the US (Ross Morrow et al., 2010). The projected acceleration of low carbon car uptake in the feebate scenarios also reflects empirical evidence from France where its new passenger vehicle fleet emissions have become one of the lowest in the EU since its feebate program was launched in 2007 (EEA, 2012; Schipper et al., 2011). However, the results of this study seem to differ from Ryan et al. (2009) who concluded that registration taxes in place between 1995-2004 did not have an important impact on the CO_2 emissions intensity of the new passenger car fleet over and above the effects of circulation and fuel taxes. Any differences between studies can be explained by different settings (e.g. socio-economic and political, prevailing pricing and taxation, vehicle fleet characteristics), policy setups and analytical methods used (e.g. probabilistic vehicle stock modeling in this study vs. ex-post analysis vs. macro-economic modeling). For instance, Ross Morrow et al. (2010) concluded that purchase tax credits *on their own* are expensive and ineffective at reducing emissions. This is in line with the results on scrappage rebates explored in this study, although of course there are differences in setup (e.g. Ross Morrow explored credits based on fuel consumption while this study based them on CO_2 performance) and context (US vs. UK). Furthermore, the registration taxes investigated in Ryan et al. (2009) were quite different in design and ambition than the ones modeled here. The French case has also been reflected in this study where the ‘high’ ambition feebate policies resulted in subsidies significantly outweighing fees *in the longer term*. The UK Government would need to adjust size and timing of rebates and fees over time – as has now happened in France – to ensure economic and political feasibility. Overall, we would argue that this study adds to the evidence base by showing that if carefully designed, monitored and adjusted, a combination of credits and fees can counter these problems by controlling overall transport costs, demand effects and tax revenues.

The result that the more ambitious feebates were most successful amongst the policy scenarios modeled here in reducing *cumulative* GHG emissions (Figure 8) is partly due to the rate of change in the short to medium term. This has important policy implications for the next decade as reducing cumulative emissions – the area under the curve – is a more important goal of climate change mitigation than meeting future annual emissions targets.

The 'medium' ambition feebate policy (CPT2) represents perhaps the most balanced design of all the policy scenarios modeled here: feebate revenues are sizeable; net revenues (including fuel duty losses) are similar to the baseline; low carbon technology uptake is considerable and, crucially, starts early; and GHG emissions reductions are better than any of the alternative road tax and scrappage schemes. This is coupled with the added benefit of marginally lowering car use (as opposed to a marginal increase in CPT3 due to private motoring costs falling in the longer term). In contrast, the balance does not seem to be right when increasing the top rebate for low carbon cars from GBP2,000 (CPT2) to GBP4,000 (CPT2a). While the scheme with the higher top rebate accelerates the take-up of BEV cars instead of efficient diesel ICV and gasoline HEV, it also increases overall car ownership so that life cycle GHG emissions savings are lower than in CPT2. This of course is dependent on the carbon content of road transport electricity, which as mentioned above does not vary between scenarios and is still around 400gCO_2/kWh in 2030 and beyond.

The modeling also suggest that the potential rebound effect that arises whenever consumers buy more fuel efficient cars, thus face a *lower* cost per km and travel longer distances in response, is not hugely significant. This supports previous work that suggests rebound effects may diminish over the short and longer term due to rising real income and falling fuel prices (de Haan et al., 2009; Small and Van Dender, 2007) which is largely consistent with the rates of GDP growth and modest oil price increases used in the modeling for this study. However, future values for rebound effects will crucially depend on how fuel prices and real income growth will evolve over time.

While we were not attempting to make economic comparisons between scenarios (usually by measuring the 'social welfare'), we could meaningfully compare government revenue streams implied by different scenarios. Clearly the fiscal incentives considered here can have significant effects on government revenue streams, as recent empirical evidence suggests (Diem, 2011; Rogan et al., 2011). Additional tax burdens may irritate consumers, especially if the taxes are not ring-fenced for improving, say, the public transport system, or if the winners and losers are not distributed equally across social strata and geography. The welfare and distributional impacts of any fiscal instrument with respect to wider impacts on congestion, local air pollution and revenue distribution were beyond the scope of this study but would be an important part of further policy evaluation.

The sizeable and negative NPVs of GBP-25 billion (CPT3a) and GBP-30 billion (CPT3) for the 'high' ambition feebate schemes would undoubtedly prompt the UK Government to fill the revenue gap by other means, e.g. through raising fuel duties or road taxes. As the results suggest, designing an incentive structure that (a) satisfies governments and consumers and (b) is flexible and dynamic presents an important challenge, mainly due to the uncertainty regarding consumers' response to fiscal pricing incentives. This uncertainty makes it difficult to determine the optimal feebate rates and timing of the tightening by emissions band (Gallagher et al., 2007). However, we and others (BenDor and Ford, 2006) believe that despite the uncertainties over market shares, it is possible to maintain a reasonable balance and control of the finances, provided that the incentive plan is flexible enough.

The results for the VED policies again highlight that grading (by fuel type, CO_2 emissions rating, first year of registration) and tightening of CO_2 limits over time are crucial in achieving the transition to low carbon mobility. The 'medium' and 'high' VED policies achieve significantly higher acceleration of low carbon technology, lower car use, lower life cycle GHG emissions and much higher revenues than the current UK VED scheme (VED1), especially in the long run. However, they are not as effective in this respect as the purchase tax/feebate schemes in the short to medium term. This could be explained by the growing evidence that consumers respond more effectively to up-front price signals than to future savings or costs. For instance, consumers claim fuel efficiency to be an important vehicle purchasing criteria, yet heavily discount future cost savings through improved fuel economy, while expecting short pay back periods (see Gross et al., 2009 for a review of the extensive literature in this area).

Scrappage incentives are distinct from the above policies as recently designed schemes have regarded any carbon reduction to be a mere additional bonus above and beyond providing “a vital stimulus for the motor industry, boosting the market and protecting jobs throughout the supply chain” (SMMT, 2010). The analysis of the simple scrappage scheme implemented in the UK in 2009, SCR1, has largely confirmed recent criticisms that a reduction of emissions from newer cars would be offset by the new vehicles being driven more, that there would be significant environmental costs associated with the production of vehicles and that fewer sales will occur after the economy has picked up (IFS, 2009). By designing scrappage schemes to be ‘greener’ and longer term, moderate emissions savings can be achieved (SCR2/3); however, this comes with a hefty price tag (of direct subsidies to industry via consumers) so may not be economically feasible for long.

6 CONCLUSION AND OUTLOOK

This paper started with the premise that there is a gap in understanding how individual fiscal policy instruments aimed at influencing consumer vehicle choice can affect low carbon technology acceleration and associated carbon emissions reductions. To fill this gap, it explored which type of taxation on low carbon passenger vehicles accelerates fuel, technology and purchasing behavioral transitions the fastest with (i) most life cycle GHG emissions savings, (ii) potential revenue neutrality for the UK Treasury and (iii) no adverse effects on car use.

It employed the UKTCM modeling framework to develop nine core scenarios and five scenario variants of fiscal policies primarily affecting car ownership and their effects on low carbon technology uptake, car use, life cycle energy use and carbon emissions. The UKTCM was the tool of choice for this analysis because it integrates a household car ownership model, vehicle consumer choice model, vehicle stock evolution model and vehicle and fuel life cycle emissions model in a single scenario modeling framework. Most importantly, this paper has adopted a consistent modeling framework to compare various instruments on the basis of their whole life cycle emissions, including potential changes in the way in which cars are used, together with the impacts on government tax revenue. Consideration of these wider impacts has important implications for the rate with which cumulative carbon reduction budgets are managed and each instrument’s likely political feasibility. The rate with which CO_2 limits need to be tightened in order to keep pace with fuel efficiency improvements, avoid net revenue losses but maintain public acceptability demands consideration of potential future scenarios in this way. In addition, the modeling framework allows some evaluation of potential flanking policies, such as increases in the cost of electricity used in road vehicles.

Of the policy incentives and ambitions modeled for this paper, the car purchase feebate policies are shown to be the most effective in accelerating low carbon technology uptake, reducing life cycle greenhouse gas emissions and, if designed carefully and adjusted over time, can avoid overburdening consumers with ever more taxation whilst ensuring revenue neutrality. Highly graduated road taxes (or VED) can also be successful in reducing emissions; but while they can provide handy revenue streams to governments that could be recycled into accompanying low carbon measures, they may face opposition by the driving population and car lobby groups for increasing private motoring taxes once again. Scrappage schemes are found to save little carbon, particularly when direct and indirect impacts are considered and may even increase emissions on a life cycle basis. Thus in order to achieve the transition to a low carbon transport system governments should focus on designing incentive schemes with strong up-front price signals that reward ‘low carbon’ and penalise ‘high carbon’. However, there is more work to be done to assess the effects of a *combination* of policies. For instance, a VED policy such as VED3 might complement a purchase feebate policy (e.g. CPT3) and help fill the revenue hole. The UKTCM could easily be used for such an analysis; hence we consider this as a first step for future work.

In this analysis, the impact of rebound as a result of changes to marginal driving costs together with the attempts to lock in these savings by increasing electricity tariffs made small but important differences to the carbon and revenue calculations. In reality, the strength of the behavioral response to changes in marginal driving costs is dependent on price differentials across different fuels and any parallel changes in incomes, both of which were not altered in the scenarios adopted here over and above changes in the Reference case. In addition, GHG emissions will be dependent on the carbon intensity of the grid which never went below 400gCO_2/kWh and was not altered between scenarios. The underlying assumption of the scenarios modeled here is that apart from vehicle taxation levels no other factors are changed relative to baseline (REF). There is more to be done to understand the links with other fiscal policies, notably fuel duty on future transport fuels such as electricity and hydrogen (both assumed to attract zero duty) and VAT on cars. These parameters are able to be tested in further modeling runs. More challenging, however, is the ability to reflect non-price determinants of consumer behavior in the modeling framework such as the potential for different emotional responses depending on the form, timing, payment method, magnitude and familiarity of the fiscal instruments and thresholds or tipping points which lead to disproportionate reactions. In addition, spatially disaggregated analysis within a life cycle assessment framework would reveal important distributional impacts with respect to congestion and air pollution impacts. Further work could also look into the recycling of any large amounts of tax revenues to other low carbon policies such as those aimed at reducing the need to travel, or travel by more sustainable modes (Cairns et al., 2008). The focus of this work was on cars; yet the analysis could easily be applied to vans, trucks and buses where pricing plays perhaps an even larger role. Finally, more work needs to be done to understand system-wide energy implications of low carbon transitions in transport as well as other sectors, in particular when looking at the likely electrification of road and rail transport (Anable et al., 2012).

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