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MAY 2017

RESOURCES FOR THE FUTURE

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Abstract

Policymakers have been considering vehicle and fuel taxes to reduce transportation greenhouse gas emissions, but there is little evidence on the relative efficacy of these approaches. We examine an annual vehicle registration tax, the Vehicle Excise Duty (VED), which is based on carbon emissions rates. The United Kingdom first adopted the system in 2001 and made substantial changes to it in the following years. Using a highly disaggregated dataset of UK monthly registrations and characteristics of new cars, we estimate the effect of the VED on new vehicle registrations and carbon emissions. The VED increased the adoption of low-emissions vehicles and discouraged the purchase of very polluting vehicles, but it had a small effect on aggregate emissions. Using the empirical estimates, we compare the VED with hypothetical taxes that are proportional either to carbon emissions rates or to carbon emissions. The VED reduces total emissions twice as much as the emissions rate tax but by half as much as the emissions tax. Much of the advantage of the emissions tax arises from adjustments in miles driven, rather than the composition of new car sales.

Key Words: CO_2 emissions, vehicle registration fees, carbon taxes, vehicle excise duty, UK

JEL Codes: H23, Q48, Q54, R48

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1. Introduction

Transportation accounts for about 14 percent of global greenhouse gas emissions and 23 percent of carbon dioxide (CO_2) emissions (IPCC 2014). To reduce these emissions, many countries have adopted tighter fuel economy and CO_2 emissions rate standards for passenger vehicles, as well as other policies such as plug-in vehicle subsidies.[1] Countries adopting such standards and policies account for about three-quarters of global passenger vehicle fuel consumption and include developed and developing countries.

Many countries are redesigning their vehicle tax systems to complement fuel economy standards. This approach is particularly common in Europe, where vehicles are often subject to a sales tax at the time of purchase, as well as annual registration (circulation) fees. For example, France offers subsidies for purchasing vehicles with low CO_2 emissions rates and imposes substantial taxes on purchasing vehicles with high emissions rates. In Germany, a vehicle's circulation tax increases linearly with its emissions rate, whereas in the UK, it is a step function of the emissions rate.

The literature has typically estimated the average effect of CO_2 taxes on new vehicle registrations, finding that the taxes reduce average new vehicle emissions rates (e.g., Adamou et al. 2012; Ciccone 2014; D'Haultfœuille et al. 2014; Konishi and Meng 2014; Klier and Linn 2015; Alberini and Bareit 2016; Yan and Eskeland 2016). A common approach to estimating consumer responses to vehicle taxes is to assume that consumers respond to the vehicle tax the same way they respond to the vehicle price. This assumption has been adopted by Adamou et al. (2014), D'Haultfœuille et al. (2014), and Grigolon et al. (2015), among others. However, Brockwell (2013), Li et al. (2014), Rivers and Schaufele (2015), and D'Haultfœuille et al. (2016) provide evidence contradicting this assumption.[2] Moreover, some studies assume that consumers respond similarly to purchase taxes as they do to discounted annual registration taxes. However, consumers could respond differently to these taxes for a variety of reasons, such as uncertainty or salience (Chetty et al. 2009). This has potentially important implications in terms of tax design.

Many countries have also considered carbon taxes.[3] One simple way to implement a carbon tax is through a fuel excise tax, and fuel excise taxes are present virtually everywhere. Although some studies conclude that carbon taxes are more efficient than vehicle standards at reducing carbon emissions (Jacobsen 2013), others find that consumers undervalue the vehicle's fuel economy (Grigolon et al. 2015; Allcott and Wozny 2014). If that is the case, instruments such as vehicle taxes, subsidies, or feebates

[1] A vehicle's CO_2 emissions rate is inversely proportional to its fuel economy.

[2] In their study on feebates in France, D'Haultfœuille et al. (2016) show that 40% of the effect on emissions is due to a change in preferences, above and beyond the increase in vehicle costs. This may be because of a higher salience of taxes than prices (perhaps as a result of heavy media coverage), the perception that tax changes are more persistent than price changes, and the fact that the tax itself might convey additional information on the environmental impact of the good.

[3] Because there is a fixed, proportional relationship between CO_2 emissions rate and fuel economy, for the purposes of this paper a carbon tax can be considered equivalent to a fuel tax, the only possible difference being the point of collection (at the pump or as a yearly amount like the current registration tax).

could be more efficient than carbon taxes (Allcott et al. 2014).

In sum, policymakers aiming to reduce carbon emissions can tax vehicles or fuels, and if they tax vehicles, they must decide how to structure the system. Much of the literature has imposed strong assumptions on consumer behavior in comparing these tax approaches, and these two sets of alternatives are rarely compared explicitly with one another.

In this paper, we analyze an annual vehicle registration tax, the Vehicle Excise Duty (VED), which the UK adopted in 2001. Before adoption of the VED, annual vehicle registration taxes depended on engine size, but since 2001, taxes have depended on CO_2 emissions rates. The taxes are imposed each year the vehicle is owned and driven. There is considerable variation in VED rates over time and over different emissions levels. For instance, in April 2005, taxes ranged from £65 for vehicles with emissions rates below 100 grams of CO_2/kilometer (g/km, or about 56 miles per gallon [mpg] for a gasoline-powered car) to £165 for vehicles with emissions rates above 185 g/km (30 mpg). In May 2009, taxes ranged from £0 for vehicles with emissions rates below 100 g/km to £405 for vehicles with emissions rates above 255 g/km (22 mpg). The UK registration tax system thus penalizes vehicles with high emissions rates and provides discounts to vehicles with low emissions rates. The tax advantage for low-emissions vehicles has increased over time.

Focusing on these tax changes allows us to relax assumptions on consumer responses to vehicle taxes and fuel prices. Using a highly disaggregated dataset of UK monthly new car registrations and characteristics, we estimate the effects of the taxes on new car registrations. As in Marion and Muehlegger (2008) and Li et al. (2014), we test the assumption made by the previous literature that consumers respond equally to a change in vehicle tax and a change in vehicle price. We reject this hypothesis, which motivates a reduced-form approach that omits vehicle price as an independent variable and estimates the effect of taxes on equilibrium registrations. The tax effect is identified by variation in tax rates across vehicles and over time. This approach does not impose the assumption that consumers respond similarly to vehicle prices as to taxes, or that they respond similarly to annual registration as to purchase taxes.

We use the results to compare the effects on new registrations, tax revenue, and carbon emissions of several policies: (i) a tax based on engine size, (ii) the 2005 VED rates, (iii) the actual VED rates imposed between 2005 and 2010, (iv) a tax proportional to carbon emissions *rates*, and (v) a carbon tax (depending on both vehicle emissions rates and miles driven). We find that the actual VED has reduced emissions rates by almost 2 percent compared with the preexisting engine tax. Moreover, a carbon tax that achieves the same revenue as the VED would have reduced emissions by about twice as much, whereas the proportional tax would have reduced emissions by about half as much.

The structure of the VED explains these results. The VED severely penalizes the most polluting vehicles and greatly favors the cleanest ones, which explains why the VED causes greater emissions reductions than the proportional tax. However, the VED provides small incentives for consumers to switch among moderately polluting vehicles—and it is the latter that account for most new car registrations. A carbon tax has a similarly small effect on new vehicle choices but attains greater emissions reductions because it encourages people to reduce mileage.

The reminder of the paper is organized as follows. Section 2 provides a background of the UK vehicle registration tax scheme. Section 3 describes the vehicle registration data. Section 4 shows the estimation model

and the identification strategy. Section 5 presents the results, and Section 6 concludes.

2. Background

Before March 1, 2001, the VED depended on the size of the engine. Owners of cars with larger engine capacity paid a higher registration fee. Since that date, a vehicle is placed in a CO_2 emissions "band" that determines its tax. The higher the emissions rate, in g/km, the greater the VED amount, and the tax varies discretely across bands. Cars first registered before March 2001 continued to pay a registration tax based on engine size.

Initially, there were four bands. Band A included cars with emissions rates up to 150 g/km; band B, those with rates between 151 and 165 g/km; band C, those with rates between 166 and 185 g/km; and band D, those with rates of 186 g/km or more. In March 2002, band A was broken into bands AA (less than 120 g/km) and A (121–150 g/km), while all other bands remained unchanged. In March 2003, vehicles that emitted 100 g/km or less were placed in band AAA, those between 101 and 120 g/km remained in band AA, and those between 121 and 150 g/km continued to be in band A (see Tables 1 and 2).

In April 2005, the bands were renamed, with no changes to the emissions range for each band (see Tables 3 and 4). In March 2006, band F was split to form a new band F (186–225 g/km) and band G, which includes vehicles with emissions rates 226 g/km and higher. Major revisions to the system occurred in May 2009, when the existing bands were redefined using 10 g/km intervals for the first nine bands, and new bands were added. As shown in Tables 3 and 4, the highest band is M, with emissions rates of 256 g/km or more.[4] During this period, vehicles registered for the first time before 2001 continued to pay a tax based on their engine size, but those rates changed as well (Table 5).

In sum, over the years, the number of bands increased, the thresholds between bands changed, and the registration fee amounts were changed. The dominant trend was to increase the tax differences between low- and high-emissions vehicles. These tax changes yielded two sources of tax variation. First, in the cross section, taxes vary across cars because of differences in emissions rates. Second, the tax applied to a car with a specific emissions rate may change over time because of changes in the definitions of the bands and in the tax rates. Until 2006, diesel fuel cars paid a slightly higher VED (between £5 and £15 more) than gasoline vehicles that had the same emissions rate.

3. Data

Our main data source is a large dataset compiled by R. L. Polk & Company, where the unit of observation is a make-model-trim variant.[5] For each such unit, we have the number of new registrations in the UK each month from January 2005 to October 2010.

In this paper, attention is restricted to gasoline or diesel passenger cars, and we exclude vans and commercial or other large

[4] Starting in 2006, cars that were first registered after 2001 but before the current fiscal year may be given a slightly different tax schedule than the one shown in Table 4, which refers to new cars.

[5] A unique variant is an observation with a given make-model-trim, number of doors, market segment, body type, two- or four-wheel drive, transmission type and number of gears, fuel type, engine size, weight, length, height, number of cylinders, horsepower, fuel consumption rate, and price.

vehicles because of incomplete coverage. The excluded vehicles account for only 1.30 percent of the original sample. We are also forced to drop from the analysis variants with no price information (0.27 percent of the sample).

Although the original data are at the monthly level, we use the policy period as the time interval for our analysis to reduce measurement error arising from monthly fluctuations in vehicle registrations not related to the VED. The policy period is essentially the fiscal year and includes a unique set of VED bands and rates. The six policy periods are described in Table 6. The table shows that the policy periods exclude months in which the VED bands or rates changed during the month rather than at the beginning of the month.

We tally the number of new registrations for each make-model-trim variant over each policy period, thus forming a panel dataset where the cross-sectional unit is the make-model-trim variant. The make-model-trim variant is a highly disaggregated unit of observation; the data include 55 makes, 507 make-models, 3,130 make-model-trims, and 36,110 make-model-trim variants. The maximum panel length is six, and the panel is unbalanced because some cross-sectional units enter or exit the market during our study period.

Toward the end of our study period, new vehicle registrations declined sharply, especially after 2007 (Figure 1). This is likely due to the major recession that started in 2008, which reduced new car registrations across Europe. In our sample, a make-model has an average of about 21,245 new registrations, while a single variant has an average of about 299. About 13 percent of the variants had no new registrations during a given policy period. On average, each make has 205 different variants per period and includes vehicles with 5 different nominal VED rates per period. As we explain below, the effect of taxes on new registrations is identified by within-make and period tax variation.

On average, vehicles became cleaner over time. Figure 2 shows unweighted average CO_2 emissions rates. In less than six years, average emissions rates declined by about 30 g/km, from about 190 g/km to 160 g/km. Because the average is not weighted by registrations, the change reflects the evolution of vehicles offered in the market.[6]

Table 7 shows registrations-weighted summary statistics of the vehicles in our sample. Although the average annual VED is quite small compared with the average price of a vehicle, because it is paid during the entire lifetime of the vehicle, its discounted sum can be fairly large.[7] This table reports the real VED amount for the first year of registration of a vehicle and the total amount for an estimated vehicle lifetime of 14 years (SMMT 2016). In most cases, the VED amount is the same for all subsequent years the vehicle is registered. The one exception is that in the last period of our sample (April–October 2010), the VED had different rates for the first year of registration and for the following years.

The main statistical analysis relies primarily on the data just described, and the policy simulations incorporate data on miles

[6] The reduction in average emissions rates comes from improvements in vehicle technology. It is unlikely that such improvement is caused by manufacturers' direct response to changes in the VED for two reasons. First, the UK accounts for just 10% of the EU car market, and other European countries have different tax schemes. Second, manufacturers require time to design their vehicles, and it is difficult to predict the VED changes.

[7] With the assumptions made in our main analysis—a vehicle lifetime of 14 years and a discount rate of 6%—the discounted sum of the VED is on average about 10% of the average price of a vehicle.

traveled as well. We obtain information about annual UK vehicle mileage, vehicle characteristics, and driving costs from the UK National Travel Survey (NTS). The UK NTS is conducted each year and collects information from households about individual trips taken during a specified period, car ownership and characteristics (including miles driven each year and odometer reading), and household sociodemographics. We use six waves of the UK NTS, from 2005 to 2010, which matches the vehicle registrations dataset. The NTS sample contains 81,855 households.[8] We consider only gasoline and diesel cars owned by households, and for estimating the relationship between mileage and vehicle characteristics, we also use only observations with information on carbon emissions (49 percent of all vehicles and 31 percent of all households covered by the survey). The vast majority of these vehicles with no CO_2 emissions rates were bought before 2001, when reporting emissions rates was voluntary. Because our focus is on new vehicles bought between 2005 and 2010, dropping the older vehicles does not affect our analysis.

The NTS dataset reports the exact CO_2 emissions rate of each vehicle, as specified by the automaker, when available, but does not contain information on fuel economy. We construct the vehicle's fuel economy using data from the UK Driver and Vehicle Licensing Agency on passenger car emissions and fuel economy, taking advantage of the fact that the emissions are proportional to the vehicle's fuel consumption rate (in liters per 100 km) and that the proportionality factor is different for diesel and gasoline (see Appendix A).

4. Empirical Model

The analysis consists of two stages. First, we estimate the relationships among fuel prices, vehicle taxes, and new registrations. Second, we use the estimated relationships to simulate the effects of various tax systems. This section explains the methodology for the first stage.

The goal of the first stage is to understand the short-run effects of hypothetical changes in vehicle or fuel taxes on the registrations-weighted average CO_2 emissions rate of new cars registered in the UK. The short run refers to a period of time in which the attributes of cars in the market are fixed, or roughly one year (Klier and Linn 2015). The short-run effects of vehicle and tax changes therefore depend on the resulting changes in equilibrium registrations of each car sold in the market.

Vehicle and fuel taxes affect equilibrium registrations because they are components of the lifetime costs of owning the vehicle. For example, increasing the tax on one particular car type raises the future cost of owning the car, relative to other cars sold in the market. The tax change induces consumers to substitute away from that car toward other new cars (or to used cars), reducing the equilibrium registrations of that car. More broadly, increasing the tax of vehicles with high CO_2 emissions rates shifts consumer demand to low-CO_2-emitting cars, and reducing the equilibrium registrations-weighted average CO_2 emissions rate. The tax increase may also reduce total UK new car registrations if it causes consumers to purchase a used car or forgo a purchase altogether. Regardless of the magnitude of this effect, increasing the tax on cars with high emissions rates reduces the registrations-weighted average emissions rate of new cars.

[8] We form multiyear cross sections, as the households interviewed as part of the UK NTS are different every year.

The empirical estimation strategy follows a reduced-form approach similar to that taken by Klier and Linn (2015) and Alberini and Bareit (2016) for other European countries. In our regressions, the dependent variable is the log registrations by model-trim variant *i*, make *m*, and period *t*, normalized by the number of months in the policy period:[9]

$$\ln(REG)_{imt} = \beta \ln(VED)_{imt} + \delta \ln(FUELCOST)_{imt} + \mathbf{x}_{im}\boldsymbol{\theta} + \alpha_{mt} + \varepsilon_{imt} \quad (1)$$

where VED is the discounted flow of the annual registration tax in 2005 GBP.10 The variable FUELCOST is the fuel cost per 100 km, which depends on the price of fuel (gasoline or diesel, in 2005 GBP) and the fuel consumption rate of the car. The fuel costs are proportional to the discounted flow of fuel costs over the lifetime of the vehicle under the assumption that fuel prices follow a random walk (Grigolon et al. 2015). The vector x contains vehicle attributes such as engine size, horsepower, weight, length and height, and fixed effects for body type, number of doors, type of transmission, number of gears, gasoline or diesel fuel, number of cylinders, and whether two- or four-wheel drive. We also include a dummy for vehicles emitting 100 g/km or less.11 The vehicle attributes control for supply-side changes during this period, such as manufacturer responses to the EU-wide CO2 emissions standards and technological progress. The make-period fixed effects control for unobserved and potentially time-varying characteristics at the brand level, such as consumer perceptions of brand quality.

We estimate equation (1) by ordinary least squares, and the VED and fuel cost coefficients are the coefficients of interest. Because an increase in tax or fuel costs reduces demand for that car, we expect the coefficients to be negative. The VED coefficient is identified by cross-sectional and time-series variation in CO_2 emissions rates interacted with time-series variation in tax rates. Likewise, the fuel cost coefficient is identified by cross-sectional and time-series variation in fuel consumption rates, interacted with time-series variation in tax-inclusive fuel prices.

[9] If a make-model-trim variant is introduced after the beginning of the policy period or is withdrawn from the market during that policy period, we normalize the registrations by the number of months that the make-model-trim variant is offered within that policy period. In some cases, the VED changes occurred in the middle of a month. We remove from the original dataset the months in which this occurs, as we cannot assign the registration to a specific tax rate, and adjust the normalization of the registrations accordingly. The months removed are March 2006, March 2007, and March 2008.

[10] Calculating this variable requires assumptions on vehicle lifetime, discount rates, and expectations of future VED rates. We assume a vehicle lifetime of 14 years, which is consistent with the average scrappage age estimated by the Society of Motor Manufacturers and Traders (SMMT 2016). As in Allcott and Wozny (2014) and Grigolon et al. (2015), we use a discount rate of 6%. Finally, in our framework, consumers expect VED rates not to change over the years. This is reasonable because in practice, the VED rates for vehicles have changed little after those vehicles were purchased (see Appendix C). The only exception to this assumption is the period at the end of our sample, from April 2010 to October 2010, when the government made changes to the rate for the first year of registration but kept the rates in later years unchanged.

[11] In the first year of the sample, there were no cars in the market emitting 100g/km or less, and the share of these vehicles in total registrations never rises above 1%. Because the VED for these cars equals zero, we add 1 to the discounted VED flow. The dummy variable for these vehicles captures the entrance of these new cars into the market.

Including make-period interactions and vehicle attributes controls for other demand shifters that might be correlated with the VED and fuel costs. At the same time, the tax and fuel cost coefficients are identified by consumer substitution across a broad range of vehicles. That is, the coefficients are identified while imposing few assumptions on substitution patterns.

One concern whenever one exploits tax variation is whether the public anticipates the tax changes. For example, anticipating a future tax for high-CO_2-emitting vehicles, consumers could decide to purchase such vehicles before the tax increase. This behavior would bias estimates of the effects of taxes on registrations, similarly to the bias introduced by anticipated fuel tax changes (Coglianese et al. 2017). Based on our reading of Her Majesty's Treasury documentation of each year's budget and on examining news coverage about the budget and VED debate prior to the final budget approval, we believe that anticipation effects are unlikely to be important in this setting (see Appendix C).

We conduct several other robustness checks of the baseline specification. For example, we assess the sensitivity of the estimates to different discount rates used to construct the VED variable. We drop models with the top 1 percent of new registrations in each period to test whether the estimates are driven by the top-selling models or reflect consumer substitution across a broad range of models. We also drop the month preceding and the month following the time when the new VED becomes effective.

Implicit in equation (1) is that the baseline specification identifies the tax and fuel cost coefficients from consumer substitution within brands. Given the magnitude of VED variation across cars and over time, it may be unlikely for VED variation to induce substitution between vehicles that are much different from one another. However, a potential concern with the baseline version of equation (1) is that it may not control for all unobserved car attributes that are correlated with the VED or fuel costs. To address this concern and take advantage of the fact that consumers may substitute across similar vehicles in response to VED changes, as an alternative to the baseline we generate price categories with £500 intervals and control for category-period fixed effects rather than make-period fixed effects.

Before turning to the empirical estimates, we note that many earlier studies of vehicle taxes and CO_2 emissions have estimated structural demand models. Typically, these studies assume that consumers derive disutility from fuel costs as well as the price of the vehicle, where the price includes all taxes paid at the time of purchase or subsequently. Identification is ensured through variation in vehicle prices or taxes (Adamou et al. 2012, 2014; D'Haultfœuille et al. 2013; Huse and Lucinda 2014; Grigolon et al. 2015; Stitzing 2016).

By combining the vehicle taxes and prices into a single variable, these studies assume that consumers respond similarly to vehicle price and tax changes, although salience or other factors may cause consumer responses to differ (Chetty et al. 2009; Marion and Muehlegger 2008). In Appendix B, we use the methodology of Marion and Muehlegger (2008) and Li et al. (2014) to test the null hypothesis that consumers respond equally to the discounted flow of registration taxes and the vehicle price. We find that consumers respond more to taxes than to equivalent car price changes, invalidating the assumption made in these studies. Our results support the reduced-form approach taken in this paper, which identifies the tax coefficient entirely from *actual* tax variation, rather than a mixture of tax and car price variation as in the other studies.

5. Results

5.1. Estimation Results

Regression results for equation (1) are presented in Table 8. All standard errors are clustered at the make-policy-period level. The first column shows the key coefficients from our main specification of equation (1). In our main specification, the VED elasticity is –0.296. This value is within the range of the tax elasticities in Klier and Linn (2015) for France, Germany, and Sweden.[12]

Results from various robustness checks are displayed in columns 2–5. Specifically, columns 2 and 3 use discount rates of 10 percent and 0 percent, respectively, instead of 6 percent. In column 4, we drop the vehicle models that rank in the top 1 percent of new registrations. In column 5, we drop the month before and after any VED changes. Finally, in column 6, we use fixed effects at the price-by-period level, using a price range of £500.

The VED coefficient estimate is similar across all columns, ranging from –0.232 to –0.373. All VED coefficients are statistically significant at the 1 percent level. Our policy simulations below are thus based on column 1.

5.2. Policy Scenarios

We wish to understand the effects of different tax structures on vehicle registrations, tax revenues, and emissions. We adopt as baseline the engine size–based registration tax, and we use the estimation results to predict vehicle registration shares between March 2005 and October 2010 under four alternatives to the baseline: (i) using the actual VED rates adopted in that period; (ii) keeping the 2005 VED rates throughout the sample; (iii) imposing a registration tax proportional to carbon emissions rates; and (iv) levying a carbon tax.[13]

Comparing i and ii illustrates the effects of the changes in tax rates that occurred after 2005, and comparing iii and iv with ii illustrates the effects of alternative systems. To enable direct comparisons among the actual VED, the emissions rate tax, and the carbon tax, we calibrate the policies to achieve the same revenue. The proportional tax is £0.825 per g/km, and the carbon tax is £63 per ton of CO_2. Consistent with the assumption implicit in our model (that substitution occurs solely within a make), we normalize registrations at the make-by-period level, allowing shares to change within each make and period, but not across them. We assume the lifetime of any vehicle to be 14 years (see Appendix A). The calculation of the proportional tax and carbon tax rates is described in Appendix D.

To calculate total emissions for the baseline and four other scenarios, we assume that all vehicles are driven the average annual mileage observed in the UK fleet according to the NTS (see Appendix A). Supporting this assumption is the fact that mileage is weakly correlated with carbon emissions rates: the correlation between the two variables is 0.09 for new cars purchased between 2005 and 2010, and 0.07 for cars of any age still registered during the same period. In addition, Table 9 shows that the distributions of annual

[12] These are –0.417, –0.301, and –0.244, respectively.

[13] For comparison, the value of carbon suggested by the UK government at the time was £25 and £76 per ton CO_2 in 2009 for sectors not included in the European Union Emissions Trading System (EU ETS). These figures become £30 and £90 per ton CO_2 in 2020 (in 2009 GBP). The transportation sector is included in this group. Note that these rates are much higher than the EU ETS prices, which ranged between £11 and £26 per ton CO_2 in 2009 and between £14 and £31 per ton CO_2 in 2020 (DECC 2009).

mileage within emissions rate classes are similar.

Figures 3–5 display summaries of the tax liability by vehicle group under the baseline engine tax, VED, emissions rate tax, and carbon tax in different periods. These totals are expressed in 2005 GBP, but we do not discount the future years' amounts. We weight cars by the number of registrations predicted by equation (1). The 45-degree line in Figures 3–5 helps identify which vehicles would be taxed more or less under the different schemes. We consider two periods: April 2005–March 2006 and May 2009–March 2010.

Figure 3 compares the VED with the engine size–based tax in these two periods. Within each of the two engine size categories, there is considerable variation in VED rates. The majority of vehicles pay more under an engine size tax; vehicles with large engines and low emissions are taxed less under the VED scheme.

Figure 4 contrasts the VED with the proportional tax. In the earlier period, many vehicles are close to the 45-degree line, and the VED scheme is very close to a proportional tax for many vehicles. The exceptions are very polluting cars, which would generally be taxed less under the VED than under a proportional tax. A group of low-polluting cars is taxed less under the VED as well. Between May 2009 and March 2010, the VED imposed a much higher tax on high-polluting vehicles than the proportional tax and offered generous discounts to low-polluting vehicles. Differences between the VED and the proportional tax are less pronounced for medium-emissions vehicles (121–185 g/km).

Finally, Figure 5 displays the VED vis-à-vis the carbon tax. Under the assumption that all vehicles are driven the same mileage, the only difference between a proportional tax and a carbon tax is that in the latter case individuals can reduce their mileage to lower their tax liability. For this reason, the graphs look very similar to Figure 4 and the same considerations apply.

5.3. Policy Simulations

Table 10 displays the predicted vehicle registration shares by VED band for the different tax schemes over our entire study period. Table 11 reports the percentage changes with respect to the engine size–based tax. The VED, the proportional tax, and the carbon tax all reduce the share of new registrations of high-polluting vehicles and increase the share of low-polluting vehicles.[14] The magnitude of the effect is the largest for the actual VED and is substantial in percentage terms but small in absolute terms. Unlike the other policies, the VED disproportionately penalizes very high-polluting vehicles and favors very clean vehicles, but because these vehicles account for a small share of new registrations, the overall effect is limited.

Table 12 shows the differences in total tax real revenues between the engine size–based tax, the 2005 VED rates, and the actual VED.[15] Compared with the engine size tax, both VED schemes generate less revenue: during its lifetime, each vehicle would pay on average £308 less under the actual VED (–17.19 percent) and £354 less with the 2005 VED rates (–19.72 percent).

We then estimate the effects of each tax on CO_2 emissions. Table 13, panel A, shows the

[14] Market shares under the proportional tax and carbon tax are almost the same because of the assumption that all vehicles are driven the same number of miles.

[15] The proportional tax and the carbon tax generate the same revenue as the actual VED, so they are not included in the table.

effects on total carbon emissions during the lifetime of a vehicle registered between April 2005 and October 2010. Compared with the engine size tax, all other policies reduce carbon emissions. The magnitude of the effect varies: the effect of a proportional tax (–0.56 percent) and of the 2005 VED (–0.46 percent) is smaller than the effect of the actual VED (–1.64 percent). The actual VED had a larger effect on emissions rates than the proportional tax or the 2005 VED. A carbon tax would have reduced emissions by about twice as much as the VED did (–3.72 percent).

The actual VED has a larger effect on emissions than the emissions rate tax because the VED creates stronger incentives in favor of very clean cars and against very polluting cars. Hence, a proportional tax is less effective than the VED at reducing emissions.[16] Under the carbon tax, consumers can decrease their total tax liability by switching to a different type of car or reducing miles driven. Our calculations, which assume a mileage elasticity of –0.1803 based on UK NTS data calculations (see Appendix A), suggest that changing miles driven reduces emissions more than changing the composition of new registrations. An important caveat to those conclusions is that our model is conservative by construction, in that it assumes that changes in market shares occur only within each make. Moreover, we consider only small changes in the registration taxes.

[16] It is, however, possible to envision cases where the proportional tax is more effective than the VED. Because the proportional tax is continuous but the VED is not, under the former, consumers have the incentive to switch to cleaner vehicles within the same VED band. This would not happen under the VED, as the tax rate is the same within a band. Our result is the combination of this effect and the loss of tax incentives (disincentives) for very clean (very polluting) vehicles.

In Table 13, panel B reports the results of sensitivity analyses for the carbon tax, where we change some of the parameter assumptions (see Appendix D). Reducing miles driven plays a more important role than changes in vehicle shares toward reducing total emissions. Assuming different lifetime mileages affects our results, but the carbon tax always attains larger emissions reductions than the other policies.

6. Conclusions

This paper compares several actual and hypothetical tax systems for reducing new car CO_2 emissions in the United Kingdom. To conduct this analysis, we first estimate the effects of vehicle taxes and fuel prices on new car registrations using data covering the UK new car market between 2005 and 2010. The tax variation arises from the VED, a scheme introduced in 2001 that links a car's annual registration tax to its CO_2 emissions rate. The scheme has been revised multiple times since its inception. Using a reduced-form approach, we estimate an elasticity of new car registrations to taxes of –0.296. This coefficient is statistically significant and robust to a series of specification checks.

We use these empirical estimates to assess the effectiveness of the VED at reducing emissions by comparing fleet composition and emissions between 2005 and 2010, during which time the scheme was tightened. We also compare the current scheme with the previous engine size–based registration tax and with hypothetical systems that tax vehicles directly in proportion to their emissions rate or their *total* CO_2 emissions.

We find that the VED causes substantial changes in registrations of the least- and most-polluting vehicles. However, these changes in registrations do not cause a large change in the average emissions rate across new cars, because the least- and most-polluting cars represent a small share of the overall market.

The VED provides comparatively little incentive for consumers to switch among vehicles with moderate emissions rates.

We also use our estimates to predict the effects of either a tax that is strictly proportional to emissions *rates* or a tax on total emissions—that is, a carbon tax. We set the tax rates of the proportional and the carbon tax to yield the same revenue as the VED and show that all three policies would reduce aggregate tax liability, compared with the pre-VED engine size–based system. The VED reduces total emissions by 1.64 percent, whereas a proportional tax would decrease emissions by about one-third as much, 0.56 percent. A carbon tax would reduce emissions by about twice as much as the VED, 3.72 percent. The effect of the carbon tax on emissions is almost entirely due to a decline in miles driven. Switching to a carbon tax imposed on drivers would thus provide, at the same or lower aggregate cost for the taxpayer, a stronger reduction in total carbon emissions than the other policies we consider. The size of this reduction depends on the mileage elasticity to the tax and total mileage, but the carbon tax causes larger emissions reductions than the other taxes under a wide range of parameter assumptions.

We conclude by noting several limitations of our study. We do not have registration data and information on emissions before 2001 (the year the VED was introduced), so our identification relies on the variations in the registration tax over time and across vehicles, and on the reclassification of vehicles into different VED bands. We can make predictions about the effect of *small* changes in the tax rates on vehicle shares and emissions but do not consider drastic modifications of the policy. The simulations are designed to be consistent with the variation in taxes and fuel prices used to identify the empirical model.

Another caveat is that we do not consider explicitly the hypothesis of a supply response to the VED—manufacturers changing vehicle characteristics to fit them into a particular VED band. We deem such behavior to be unlikely: manufacturers operate in the European market as a whole and do not change vehicles characteristics for relatively small policy changes in one country, especially when such small changes take place almost every year.

Finally, we assume that changes in the shares of registrations due to taxes occur only within a given make-model. This is a somewhat restrictive model that allows us to control for various confounding factors, but it might underestimate the effects of vehicle taxes on registrations and emissions. Our results thus represent conservative estimates of the effects of vehicle tax modifications.

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Appendix A. Fuel Economy and Mileage Estimates

The NTS used for the estimation of the mileage equation does not have information on fuel economy, only on CO_2 emissions rates. We use instead data from the UK Driver and Vehicle Licensing Agency (UK DVLA), which contains information on passenger cars from 2000 to 2010 to estimate the relationship between fuel economy and emissions rates.

In the New European Driving Cycle (NEDC), the fuel economy of a vehicle is computed from the vehicle's tailpipe CO_2 emissions. The fuel consumption rate is proportional to the CO_2 emissions rate, with the proportionality constant different for different fuels. We regress fuel economy on CO_2 emissions rates separately for diesel and gasoline vehicles, without constant terms. Table A1 shows the virtually perfect correlation between fuel economy and emissions rate. We use the regression coefficients to predict the fuel economy for each vehicle in the NTS dataset.

Next, we use the appropriate 12-month moving average of fuel costs (based on the date of the survey and the geographic location) to calculate the fuel cost in British pounds per 100 km.[17]

We then use the NTS data to regress the log yearly mileage (in km) over vehicle age in years, fuel cost in real 2005 British pounds per 100 km, engine size in cubic centimeters (cc), and fuel type.

$$\text{Log(miles)} = \alpha + \beta\ \text{Age} + \gamma\ \text{Fuel Cost} + \delta\ \text{Engine Size} + \theta\ \text{Fuel Type} + \varepsilon \qquad \text{(A1)}$$

Because the NTS is a multiyear cross section, we exploit the variation in age and mileage of the different vehicles surveyed. The results of the mileage regression are shown in Table A2. As expected, mileage decreases with fuel cost and vehicle age, but it increases with engine size. Using the sample mean of the fuel cost, we estimate a mileage elasticity of –0.1803 with respect to fuel cost.

Finally, we calculate total mileage during the lifetime of a vehicle. According to the Society of Motor Manufacturers and Traders, the average scrappage age in the UK in a given year is between 13 and 14.5 years.[18] We do not have disaggregated information by vehicle characteristics, so we assume that all vehicles in our dataset have a lifetime of 14 years.

To calculate the lifetime average mileage used in our main calculations, we simply multiply the average yearly mileage of our sample in the NTS by 14 (presumed lifetime of the vehicle). We use the age coefficient from our mileage model to calculate the mileage for each single year of life of a vehicle. We find out that the average car is driven about 187,557 km during its lifetime. To calculate the mileage for each year in the vehicle lifetime, we use the age coefficient from Table A2. When estimating the discounted flow of the revenue equivalent carbon tax, we assume people are perfectly aware how much they will be driving in the future (i.e., they will be driving less and less when their car gets old).[19]

[17] The geographic subdivisions used are the Government Official Regions: normally, North East, North West and Merseyside, Yorkshire and Humberside, East Midlands, West Midlands, Eastern, Greater London, South East, South West, Wales, and Scotland. Northern Ireland is not included in the database.

[18] http://www.smmt.co.uk/2014-sustainability/environmental-performance/end-life-vehicles/.

[19] When we assume that consumers use the mileage of the first year to predict mileage in the future years (i.e., they overestimate it), all the results for the carbon tax look very similar.

An alternative way to calculate total mileage is to sum together the average yearly mileage of our sample for each vehicle age (up to the 14th year). The resulting lifetime mileage is very similar (189,700 km). Nevertheless, we use it as part of the sensitivity analysis.

TABLE A1. RESULTS FROM EMISSIONS RATES REGRESSION

	Gasoline ($g\ CO_2$/km)	Diesel ($g\ CO_2$/km)
Consumption rate (l / 100 km)	23.77***	26.49***
	(0.0300)	(0.0075)
R-squared	0.9995	0.9986
Observations	29,080	17,364

TABLE A2. RESULTS FROM MILEAGE REGRESSION

	Log km/year
Age	–0.0230***
	(0.0017)
Fuel cost (pence / 100 km)	–0.0003***
	(0.0000)
Engine size (cc)	0.0003***
	(0.0000)
Diesel	0.2277***
	(0.0120)
Constant	9.1483***
	(0.0184)
Observations	29526

Note: Results based on equation (A1). Dependent variable is the log of km driven in a year for a given vehicle in the UK NTS dataset.

Appendix B. Comparing Response to Registration Taxes and Vehicle Price

To test the null hypothesis that the coefficient on price is different from that on the (discounted flow) of registration tax payments over the course of a car's lifetime, we implement a simple modification to equation (1) based on Marion and Muehlegger (2008), decomposing the ownership cost of a vehicle in the actual price and the registration tax. We specify the regression equation

$$\ln\left(REG_{imt}\right) = \alpha_{mt} + \beta \ln\left(1 + \frac{VEDTAX_{imt}}{P_{imt}}\right) + \gamma \ln\left(P_{imt}\right) + \delta \ln\left(FUELCOST_{imt}\right) + \boldsymbol{\theta}\mathbf{x}_{im} + \varepsilon_{imt} \quad \text{(B1)}$$

where, as in our main specification, i denotes the make-model-trim variant, m the make, t the policy period, and REG the number of new units registered normalized by the number of months in the policy period. On the right-hand side of equation (B1), VEDTAX is the discounted flow of the annual registration tax (in 2005 GBP), P is the manufacturer-suggested retail price of the vehicle, and FUELCOST is the fuel cost per 100 km. Vector x contains vehicle attributes, and we also add a dummy for vehicles emitting less than 100 g/km. It is straightforward to show that if $\beta = \gamma$, then consumers respond equally to a change in price and a change in the discounted flow of the registration tax, and all future VED payments can be added to the price tag of the vehicle (Marion and Muehlegger 2008; Li et al. 2014).

We estimate regression equation (B1) using ordinary least squares (OLS) and, since the Berry model regards price as endogenous and vehicle attributes as exogenous, also by instrumenting price with the usual BLP instruments.[20] Because the price appears in two of the variables on the right-hand side, we also add the set of our BLP instruments interacted with the natural log of *VEDTAX* . Then we use an F test or Wald test to check whether $\beta = \gamma$.

The estimation results and the outcomes of the F and Wald tests from models where the shares are allowed to depend on price, fuel cost, and VED separately are displayed in Table B1. We change both the discount rate (6 percent, 10 percent, or 0 percent) and the types of instruments we use: in column 1, we use no instruments; column 2 is an instrumental variable specification using BLP instruments based on engine size, gross vehicle weight, and length; in column 3, instruments are based also on height, engine horsepower, transmission type, and fuel type; and in column 4, we construct our instrument using all the available vehicle characteristics. Clearly, whether or not we allow price to be endogenous and regardless of the discount rate used, in the majority of our specifications the null hypothesis is soundly rejected at the 1 percent level or better, implying that the effects of VED changes should not be predicted on the basis of the coefficient from the total of all costs.

[20] See Berry 1994; Berry et al. 1995; Vance and Mehlin 2009; Adamou et al. 2012, 2014; Huse and Lucinda 2014; Konishi and Meng 2014; Grigolon et al. 2015; Alberini and Bareit 2016. To construct the BLP instruments, we use the average of the natural log of the characteristics of vehicles, once for vehicles within the same make and period and once for vehicles in a different make or period. For categorical variables such as fuel type, we use the average share of vehicles. Results are very similar when we use the average of the characteristics without taking the natural log.

TABLE B1. INSTRUMENTAL VARIABLE RESULTS: TEST ON EQUALITY OF LOG PRICE AND LOG 1+(VED/P) COEFFICIENTS

Variables	(1)	(2)	(3)	(4)
		Panel A: Discount rate 0%		
LOG PRICE	–0.957***	–1.100**	–0.999**	–0.221
	(0.156)	(0.457)	(0.412)	(0.368)
LOG 1+(VED/P)	–2.519***	–2.840***	–2.947***	–2.588***
	(0.540)	(0.794)	(0.664)	(0.609)
LOG FUEL COST	–1.137***	–1.096***	–1.077***	–1.097***
	(0.168)	(0.178)	(0.172)	(0.181)
TESTSTAT	10.25	3.57	7.03	12.38
P-VALUE	0.0015	0.0587	0.0080	0.0004
		Panel B: Discount rate 6%		
LOG PRICE	–0.959***	–1.090**	–0.991**	–0.215
	(0.156)	(0.457)	(0.412)	(0.368)
LOG 1+(VED/P)	–3.414***	–3.780***	–3.945***	–3.443***
	(0.725)	(1.066)	(0.896)	(0.822)
LOG FUEL COST	–1.136***	–1.102***	–1.082***	–1.103***
	(0.168)	(0.178)	(0.172)	(0.182)
TEST STAT	13.54	5.36	9.99	14.12
P-VALUE	0.0003	0.0205	0.0016	0.0002
		Panel C: Discount rate 10%		
LOG PRICE	–0.959***	–1.084**	–0.986**	–0.211
	(0.156)	(0.457)	(0.412)	(0.369)
LOG 1+(VED/P)	–4.063***	–4.447***	–4.656***	–4.052***
	(0.858)	(1.259)	(1.063)	(0.974)
LOG FUEL COST	–1.136***	–1.106***	–1.085***	–1.106***
	(0.168)	(0.178)	(0.173)	(0.182)
TEST STAT	15.13	6.30	11.44	14.77
P-VALUE	0.0001	0.0120	0.0007	0.0001
Observations	55,782	55,782	55,782	55,782

Note: Results using model B1 and test of equality of coefficients between LOG PRICE and LOG 1+(VED/P). The dependent variable is the log of the normalized number of units sold. Column 1: OLS. Column 2: BLP instruments using engine size, gross vehicle weight, and length. Column 3: BLP instruments using also height, engine horsepower, transmission type, and fuel type. Column 4: BLP instruments using all vehicle characteristics. Robust standard errors in parentheses, clustered by make-by-period. Fixed effects at make-by-period level. P-values: *** p < 0.01, ** p < 0.05, * p < 0.1.

Because we soundly reject the null hypothesis, we cannot combine price and present and future registration tax payments and use the coefficient on price to estimate the effect of changing the registration tax system or amounts. Another implication of this result and of the variation in the VED across types of cars and over time is that we can estimate a reduced-form equation, where

log sales are regressed on the VED and other car characteristics regarded as exogenous, thus omitting car price.

Finally, we use our reduced form specification to test whether people respond equally to a change in lifetime fuel costs or lifetime VED payment. To calculate the discounted sum of fuel costs during a vehicle's lifetime, we use the default assumptions explained in Appendix A: a vehicle lifetime of 14 years and a total mileage of 187,557 km. We use the age coefficient in Table A2 to calculate the km driven each year, assuming that consumers have perfect knowledge of their future mileage. We calculate the discounted fuel costs using the usual rates of 6 percent, 10 percent, and 0 percent.

TABLE B2. RESULTS OF TEST OF EQUALITY OF COEFFICIENTS: DISCOUNTED SUM OF LIFETIME VEHICLE FUEL COSTS AND DISCOUNTED SUM OF VED COSTS

Variables	(1)	(2)	(3)
ln(SUM FUELCOST)	–1.424***	–1.425***	–1.423***
	(0.186)	(0.186)	(0.186)
ln(VEDTAX)	–0.296***	–0.294***	–0.299***
	(0.067)	(0.067)	(0.068)
Observations	55,811	55,811	55,811
Test statistics	30.85	31.04	30.61
P-value	0.000	0.000	0.000

Note: Results using model (1), using the discounted sum of fuel costs instead of fuel cost per 100km. The dependent variable is the log of the normalized number of units sold. Column 1: 6% discount rate. Column 2: 10% discount rate. Column 3: 0% discount rate. Robust standard errors in parentheses, clustered by make-by-period. Fixed effects at make-by-period level. P-values: *** p < 0.01, ** p < 0.05, * p < 0.1

In practice, we use a slight modification to equation (1), where we have the discounted sum of fuel costs instead of fuel costs per 100 km. Results in Table B2 strongly reject the null hypothesis of equality of coefficients between discounted sum of fuel costs and discounted sum of VED costs.

Appendix C. News Articles and Web Searches on the Vehicle Excise Duty

Changes in VED occurred regularly, at the beginning of each budget period, and from 2008 on, the government disclosed future changes in the VED in its budget documents. If people are informed in advance about potential changes, they can react accordingly. For instance, they can buy a high-polluting vehicle before the new rates are introduced.

We relied on two measures to assess how aware of changes in the VED the general public is. The first is the number of newspaper articles about the VED, and the second is an index of interest over time through Google searches. We wanted to see if peaks of articles and search interest occurred before the changes were implemented. That would strongly suggest that the general public is aware that changes in the VED are due shortly.

The data on newspaper articles come from LexisNexis and include 156 publications in the UK. Among those outlets, we searched for articles including "VED" or "vehicle excise duty." We considered articles from 2006 to 2010, as before that period, the exact dates of articles are not always specified.

Figure C1 shows the distribution of the news articles over time. Peaks in VED newspaper coverage generally occurred right after the VED changes—in March 2006, March 2007, March 2008, and April 2010. In May 2009, when the changes were modest, we do not observe peaks. Neither do we observe peaks in the month before a change in rates took place.

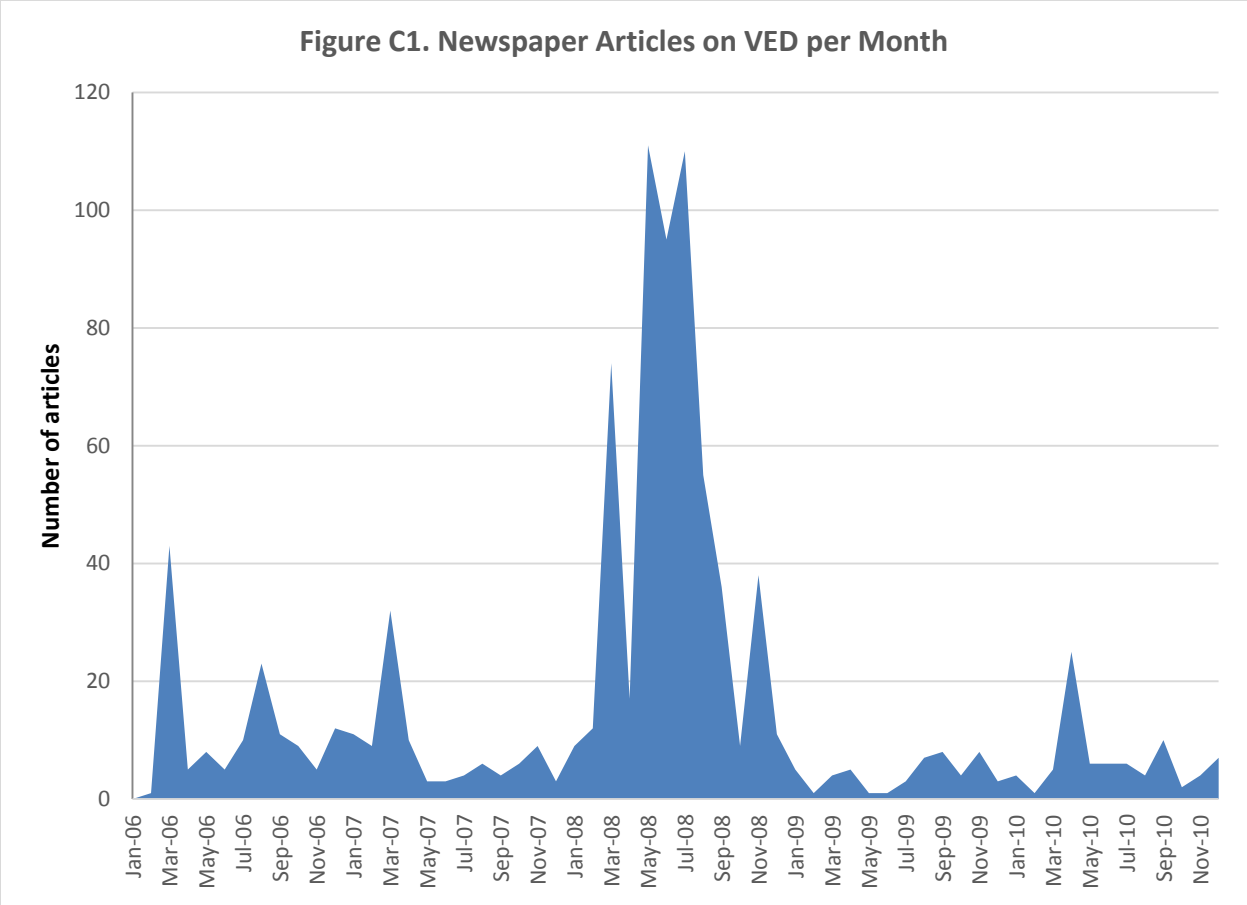
The peaks in news coverage between May 2008 and July 2008 were caused by protests against scheduled increases in the VED that hit existing vehicle owners instead of just new

vehicles. Eventually, these planned increases were scrapped in November 2008, which generated another news peak.

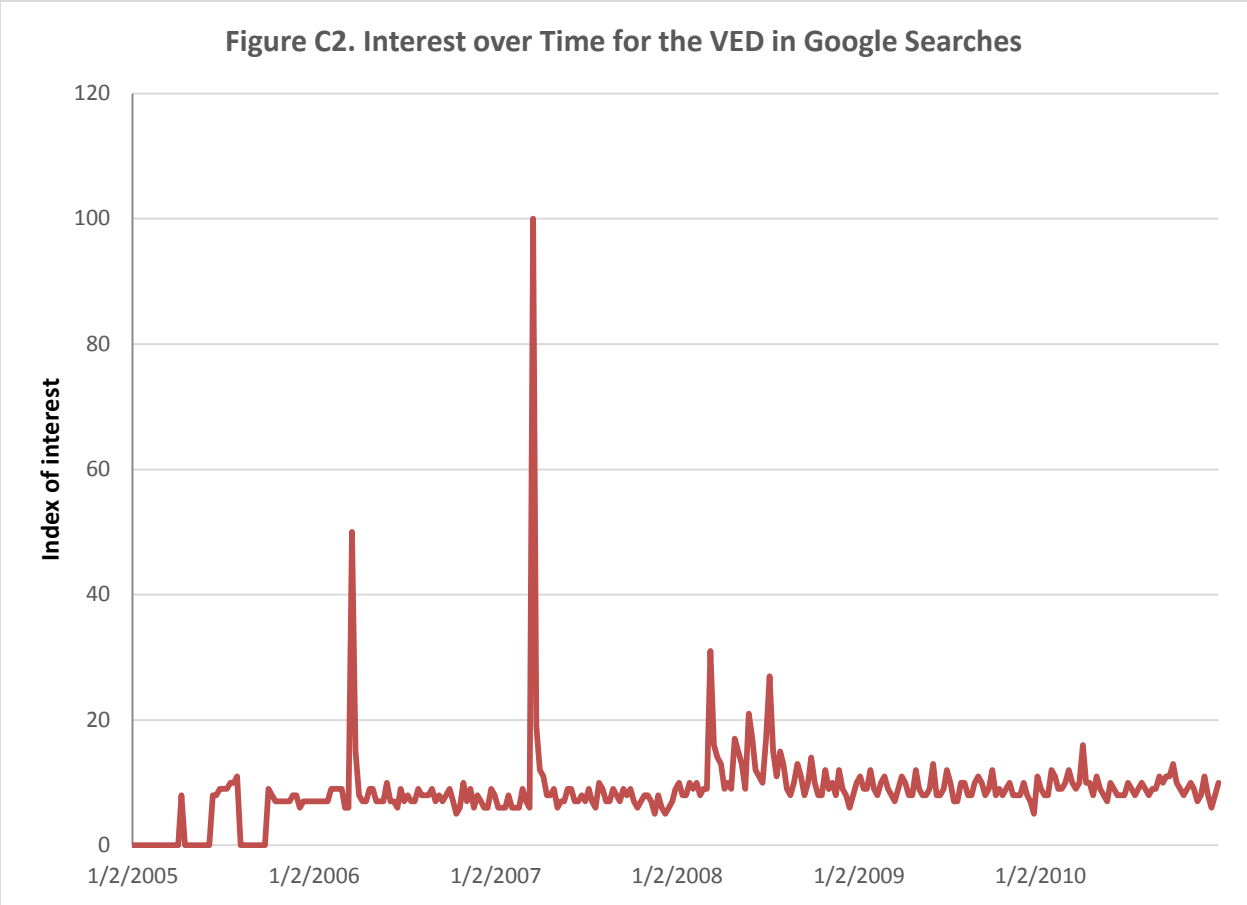
Importantly, we do not observe in the headlines or in the article contents information or speculation about future rates, with the partial exception of 2008. Similarly, we do not observe articles warning the readers about imminent changes in the VED. The majority of the articles in our dataset inform the general public about current rates.

We then look at the Google Trends index for web searches about the VED. Google provides an index for all searches related to the VED ("topic"), regardless of the exact words searched. Figure C2 shows a measure of relative interest in the VED between 2005 and 2010. Earlier data, especially for 2005, are less reliable, but we include these data for completeness.

The graph shows that changes in interest occurred the months in which changes in VED rates (2006 and 2007) occurred and in summer 2008, as seen for newspaper coverage. In general, the measure of interest is flat over time.



Source: LexisNexis



Source: Google Trends.

Appendix D. Calculation of the Proportional Tax and Carbon Tax Rates

The nominal rates for the tax proportional to the carbon emissions rates and for the carbon tax are calculated so that the total real revenue from the vehicles sold and registered between April 2005 and October 2010 is equal to that from the VED.

The revenue takes into account the whole vehicle lifetime, assumed to be 14 years (SMMT data), so the VED revenue from a single model-trim variant *i* during its lifetime is given by

$$\text{Revenue}_i = \sum_{t=0}^{13} \frac{\text{VED}_i}{\frac{HICP_i}{100}\,[1 + (2.8\,t/100)]}$$

where VED_0 is the nominal VED rate for that vehicle at the time of purchase, $\frac{HICP_0}{100}$ is the Harmonised Index of Consumer Prices at the time of purchase, and t is the age of the vehicle.

We make some assumptions on the VED rates and consumer price index following the first registration year: (i) each year the HICP increases by 2.8 points, which is the average yearly increase between 2005 and 2015; and (ii) the VED rates do not change over time, with the exception of the period April–October 2010, where at the moment of the registration, the second-year rate was set to be different from that of the first year.

The total revenue from the VED is simply the sum of the revenues from the predicted

number of new registrations. The total revenue from proportional tax is given by

$$\text{REVENUE} = \sum_{i}^{N} \tau_P \, \delta_i CO2_i REG_i$$

where

$$\delta_i = \sum_{t=0}^{13} \frac{1}{\frac{HICP_{i0}}{100} \, [1 + (2.8 \, t/100)]}$$

where τ_P is the proportional nominal tax rate in pounds per grams of CO_2/km, $CO2_i$ is the carbon emissions rate in grams per km, and REG_i is the number of predicted registrations from model-trim variant *i*.

In a similar fashion, the total revenue from the carbon tax is given by

$$\text{REVENUE} = \sum_{i}^{N} \sum_{t=0}^{13} \frac{\tau_C \, \delta_{it} CO2_i M_{it} REG_i}{1{,}000{,}000}$$

where τ_C is the nominal carbon tax rate in pounds per ton CO_2, and M_{it} is the mileage in km for model-trim variant *i* at vehicle age *t*. The mileage for each year of the vehicle's life is calculated with the methodology explained in Appendix A.

To calculate the tax rate to use for the proportional tax and the carbon tax, we use a simple algorithm with the following steps: (i) select a tax rate from a range of possible rates for the proportional or the carbon tax, (ii) predict registrations for each model-trim variant and each period (normalized by model-period) under the VED or one of the alternative policies using the main model, (iii) calculate the total revenue from the VED and from the proportional or the carbon tax, and (iv) keep the tax rate only if the absolute value of the difference between the two revenues is within the 0.1 percent of the revenue from the VED.

The revenue from the VED is estimated to be roughly £14.2 billion. In the main specification, we are assuming all vehicles are driven the average lifetime mileage, derived from the NTS data. For the carbon tax, we are using a mileage elasticity with respect to fuel cost of –0.1803 from our mileage model (see Appendix A). To predict new vehicle registrations, we are using the VED coefficient (i.e., converting the carbon tax to an amount to pay per year), and we are assuming that people anticipate their reduction in mileage due to the introduction of a carbon tax when choosing a new vehicle.

When calculating the effect of the carbon tax, we are also performing various sensitivity analyses by modifying some parameters or assumptions of the main specification: (i) using a slightly different way to calculate the average lifetime mileage (see Appendix A), (ii) assuming that new vehicle registrations are inelastic, (iii) assuming that mileage is inelastic, (iv) using the fuel cost coefficient (based on cost per 100 km) instead of the VED coefficient (based on cost during the first year) to predict new registrations, (v) using a mileage elasticity to fuel cost of –0.3, and (vi) using various percentiles of lifetime mileage from the NTS data (1st quartile, median, 3rd quartile, 90th percentile).[21]

[21] Parry and Small (2005) use a range of mileage elasticity to fuel cost between –0.2 and –0.6.

Tables and Figures

TABLE 1. VED BANDS CLASSIFICATION FOR NEW CARS BETWEEN 2001 AND 2003

CO_2 emissions rate (g/km)	Mar-01	Mar-02	Mar-03
100 or less	A	AA	AAA
101–120			AA
121–150		A	A
151–165	B	B	B
166–185	C	C	C
186 and higher	D	D	D

TABLE 2. VED RATES FOR NEW CARS BETWEEN 2001 AND 2003

CO_2 emissions rate (g/km)	Mar-01	May-02	May-03
100 or less	£100	£70	£65
101–110			£75
111–120			
121–130		£100	£105
131–140			
141–150			
151–165	£120	£120	£125
166–175	£140	£140	£145
176–185			
186–200	£155	£155	£160
201–225			
226–255			
256 and above			

TABLE 3. VED BANDS CLASSIFICATION FOR NEW CARS AFTER APRIL 2005

CO_2 emissions rate (g/km)	Apr-05	Mar-06	May-09
100 or less	A	A	A
101–110	B	B	B
111–120			C
121–130	C	C	D
131–140			E
141–150			F
151–165	D	D	G
166–175	E	E	H
176–185			I
186–200	F	F	J
201–225			K
226–255		G	L
256 and higher			M

TABLE 4. VED RATES FOR NEW CARS AFTER APRIL 2005

	CO_2 emissions (g/km)	Apr-05	Mar-06	Mar-07	Mar-08	May-09	Apr-10
A	100 or less	£65 (£75)	£0	£0	£0	£0	£0 [£0]
B	101–110	£75 (£85)	£40 (£50)	£35	£35	£35	£0 [£20]
C	111–120						£0 [£30]
D	121–130	£105 (£115)	£100 (£110)	£115	£120	£120	£0 [£90]
E	131–140						£110 [£110]
F	141–150					£125	£125 [£125]
G	151–165	£125 (£135)	£125 (£135)	£140	£145	£150	£155 [£155]
H	166–175	£150 (£160)	£150 (£160)	£165	£170	£175	£250 [£180]
I	176–185						£300 [£200]
J	186–200	£165 (£170)	£190 (£195)	£205	£210	£215	£425 [£235]
K	201–225						£550 [£245]
L	226–255		£210 (£215)	£300	£400	£405	£750 [£425]
M	256 and higher						£950 [£435]

Note: VED rates for gasoline vehicles. If rates are different for diesel vehicles, they are reported in parentheses. Rates in April 2010 are different for the first year and the following years. Rates for the years after the first are reported in square parenthesis.

TABLE 5. VED RATES FOR CARS REGISTERED BEFORE 2001 (ENGINE-BASED TAX)

Engine size	Apr-05	Mar-06	Mar-07	Mar-08	May-09	Apr-10
Up to 1,549 cc	£110	£110	£115	£120	£125	£125
Over 1,549 cc	£170	£175	£180	£185	£190	£205

TABLE 6. POLICY PERIODS USED IN THIS ANALYSIS

Policy period	Beginning	End	Duration in months (30 days)
1	Apr-05	Feb-06	9.2
2	Apr-06	Feb-07	10.2
3	Apr-07	Feb-08	10.2
4	Apr-08	Apr-09	12.2
5	May-09	Mar-10	10.1
6	Apr-10	Oct-10	6.1

TABLE 7. SUMMARY STATISTICS, APRIL 2005–OCTOBER 2010 (REGISTRATIONS-WEIGHTED)

Variable	Mean	Median	Std. deviation
CO_2 emissions (g/km)	159	153	36
Real price (2005 GBP)	11,636	10,438	6,162
Real VED tax first year (2005 GBP)	128	122	63
Real VED tax total vehicle lifetime (2005 GBP)	1,517	1,453	628
Engine size (cc)	1,731	1,598	529
Fuel consumption (L/100 km)	6.41	6.10	1.48
Vehicle weight (kg)	1,829	1,810	357

Variable	Share
Diesel vehicles	41.46%

TABLE 8. MAIN REGRESSION RESULTS BASED ON EQUATION (1)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
ln(FUELCOST)	–1.424***	–1.425***	–1.423***	–1.282***	–1.814***	–1.708***
	(0.186)	(0.186)	(0.186)	(0.187)	(0.197)	(0.210)
ln(VEDTAX)	–0.296***	–0.294***	–0.299***	–0.373***	–0.241***	–0.232***
	(0.067)	(0.067)	(0.068)	(0.073)	(0.068)	(0.072)
Observations	55,811	55,811	55,811	50,705	53,448	55,811

Note: Results using model 1. The dependent variable is the log of the normalized number of vehicles registered. Only coefficients for log fuel cost and log VED are reported. Column 1: main specification. Column 2: 10% discount rate. Column 3: 0% discount rate. Column 4: dropping top 1% models sold. Column 5: dropping the month before and after changes in VED. Column 6: using price category (£500 range) by period fixed effect. Robust standard errors in parentheses, clustered by make-by-period. Fixed effects at make-by-period level. P-values: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

TABLE 9. SUMMARY STATISTICS OF KILOMETERS DRIVEN BY EMISSIONS RATES DECILES (UK NTS DATA)

Emissions deciles	CO_2 range (g/km)	25th percentile	Median	75th percentile	Mean
1	0–136	8,046.70	12,874.72	19,312.08	14,435.20
2	137–142	8,046.70	12,874.72	16,093.40	13,608.88
3	143–149	8,046.70	12,874.72	17,702.74	14,132.49
4	150–155	8,046.70	12,874.72	19,312.08	15,175.61
5	156–161	8,046.70	12,874.72	17,702.74	14,377.19
6	162–169	8,046.70	12,874.72	17,702.74	14,331.21
7	170–179	8,851.37	12,874.72	19,312.08	14,880.07
8	180–191	8,046.70	14,484.06	19,312.08	14,919.59
9	192–216	9,656.04	14,484.06	19,312.08	15,840.88
10	217 or more	9,656.04	14,484.06	19,312.08	16,299.07

TABLE 10. PREDICTED NEW VEHICLE REGISTRATION MARKET SHARES, APRIL 2005–OCTOBER 2010

VED bands	CO_2 range (g/km)	Shares (engine size tax)	Shares (VED)	Shares (VED 2005)	Shares (proportional tax)	Shares (carbon tax)
A	100 or less	0.05%	0.30%	0.05%	0.05%	0.05%
B	101–110	2.67%	3.42%	2.82%	2.76%	2.76%
C	111–120	10.11%	12.88%	10.78%	10.44%	10.44%
D	121–130	9.11%	8.94%	9.08%	9.36%	9.36%
E	131–140	11.68%	11.41%	11.79%	11.79%	11.79%
F	141–150	12.33%	12.07%	12.47%	12.21%	12.21%
G	151–165	18.78%	18.11%	18.74%	18.85%	18.85%
H	166–175	7.71%	7.26%	7.48%	7.73%	7.73%
I	176–185	6.79%	6.50%	6.64%	6.76%	6.76%
J	186–200	8.82%	8.08%	8.50%	8.69%	8.69%
K	201–225	6.12%	5.77%	5.95%	5.92%	5.92%
L	226–255	3.16%	2.85%	3.09%	3.00%	3.00%
M	256 and higher	2.66%	2.42%	2.62%	2.43%	2.43%

TABLE 11. CHANGE IN PREDICTED NEW VEHICLE REGISTRATIONS COMPARED WITH ENGINE SIZE TAX

VED bands	CO_2 range (g/km)	VED	VED 2005	Proportional tax	Carbon tax
A	100 or less	550.38%	8.87%	8.43%	8.46%
B	101–110	28.08%	5.53%	3.44%	3.44%
C	111–120	27.40%	6.57%	3.25%	3.27%
D	121–130	–1.81%	–0.37%	2.77%	2.79%
E	131–140	–2.32%	0.87%	0.91%	0.91%
F	141–150	–2.16%	1.13%	–0.98%	–0.98%
G	151–165	–3.57%	–0.19%	0.40%	0.39%
H	166–175	–5.84%	–2.94%	0.24%	0.23%
I	176–185	–4.25%	–2.13%	–0.48%	–0.48%
J	186–200	–8.42%	–3.73%	–1.48%	–1.49%
K	201–225	–5.78%	–2.83%	–3.27%	–3.28%
L	226–255	–9.94%	–2.26%	–5.18%	–5.19%
M	256 and higher	–9.29%	–1.64%	–8.60%	–8.61%

TABLE 12. CHANGES IN REVENUE ASSOCIATED WITH DIFFERENT TAX SCHEMES

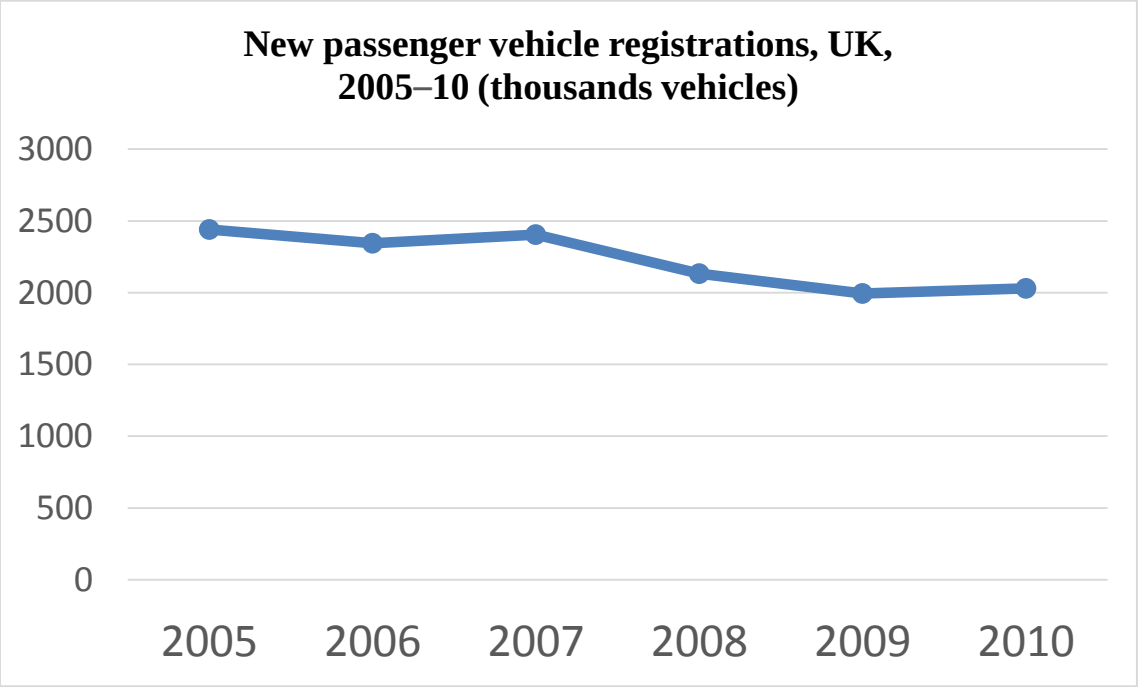
	Total lifetime fleet revenue (billion 2005 GBP)	Percentage change compared with baseline	Average change in tax revenue per vehicle (2005 GBP)
Engine size–based tax (baseline)	17.09		
VED	14.16	–17.19%	–308
VED, 2005 rates	13.72	–19.72%	–354

TABLE 13. CO_2 EMISSIONS CHANGES ASSOCIATED WITH DIFFERENT TAX SCHEMES

	Panel A: Base case, emissions		
	Total lifetime fleet emissions (million tons CO_2)	Change in CO_2 emissions	Average change in CO_2 emissions per vehicle (tons CO_2)
Engine size–based tax (baseline)	287.13		
VED	282.44	–1.64%	–0.49
VED, 2005 rates	285.81	–0.46%	–0.14
Proportional tax, same revenue as VED (£0.825 per g CO_2/km)	285.54	–0.56%	–0.17
Carbon tax, same revenue as VED (£63.0 per ton CO_2)	276.46	–3.72%	–1.12
	Panel B: Sensitivity of CO_2 emissions changes to assumptions under a carbon tax		
	Carbon tax rate (GBP per ton)	Lifetime mileage (km)	Change in CO_2 emissions
Preferred specification	63.0	187,557	–3.72%
New registrations inelastic	62.6	187,557	–3.15%
Mileage inelastic	61.0	187,557	–0.56%
Carbon tax treated as additional fuel cost (i.e., prediction is based on coefficient on fuel costs)	62.3	187,557	–2.64%
Mileage elasticity = –0.3	64.5	187,557	–5.94%
Mileage = 1st quartile	107.3	112,653	–5.94%
Mileage = median	70.1	168,980	–4.08%
Mileage = 3rd quartile	52.1	225,307	–3.17%
Mileage = 90th percentile	34.3	337,961	–2.28%

Note: See Appendix D for a detailed explanation of the different assumptions.

FIGURE 1. NEW PASSENGER VEHICLE REGISTRATIONS IN THE UK BETWEEN 2005 AND 2010



Source: European Automobile Manufacturers Associations (ACEA)

FIGURE 2. AVERAGE CO_2 EMISSIONS PER VARIANT (NOT REGISTRATIONS-WEIGHTED)

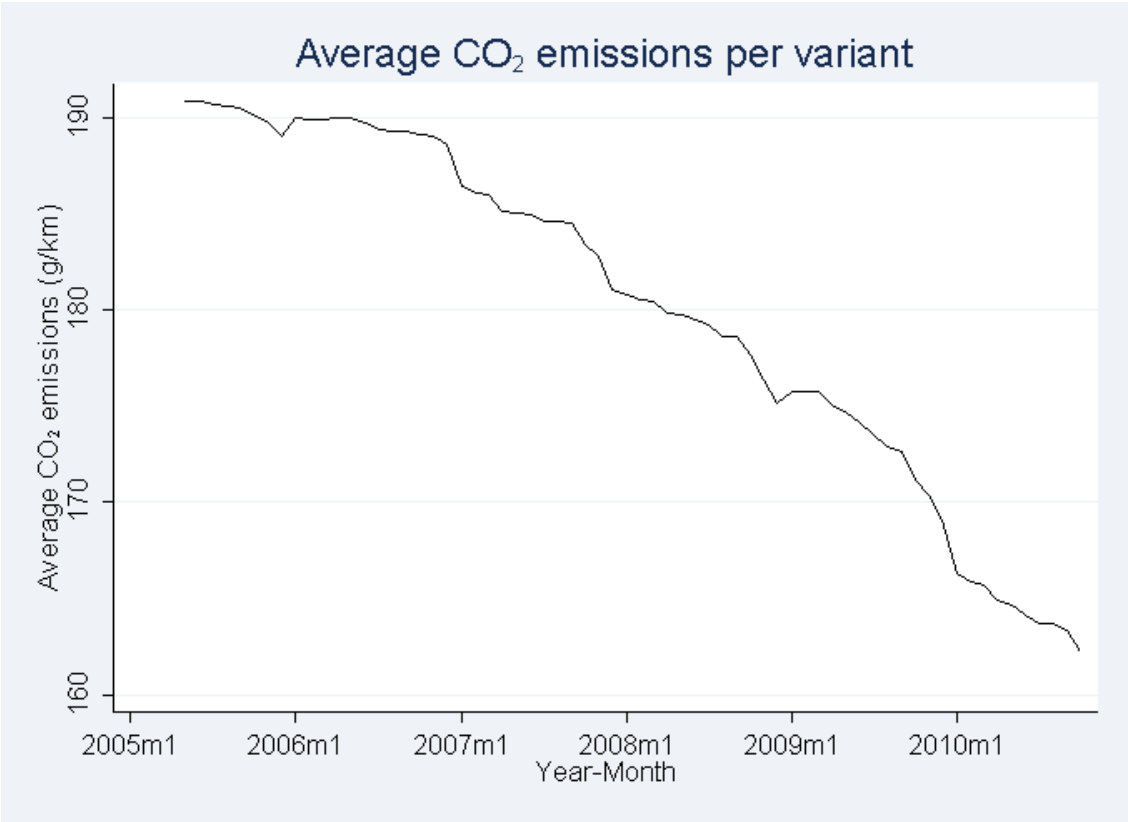
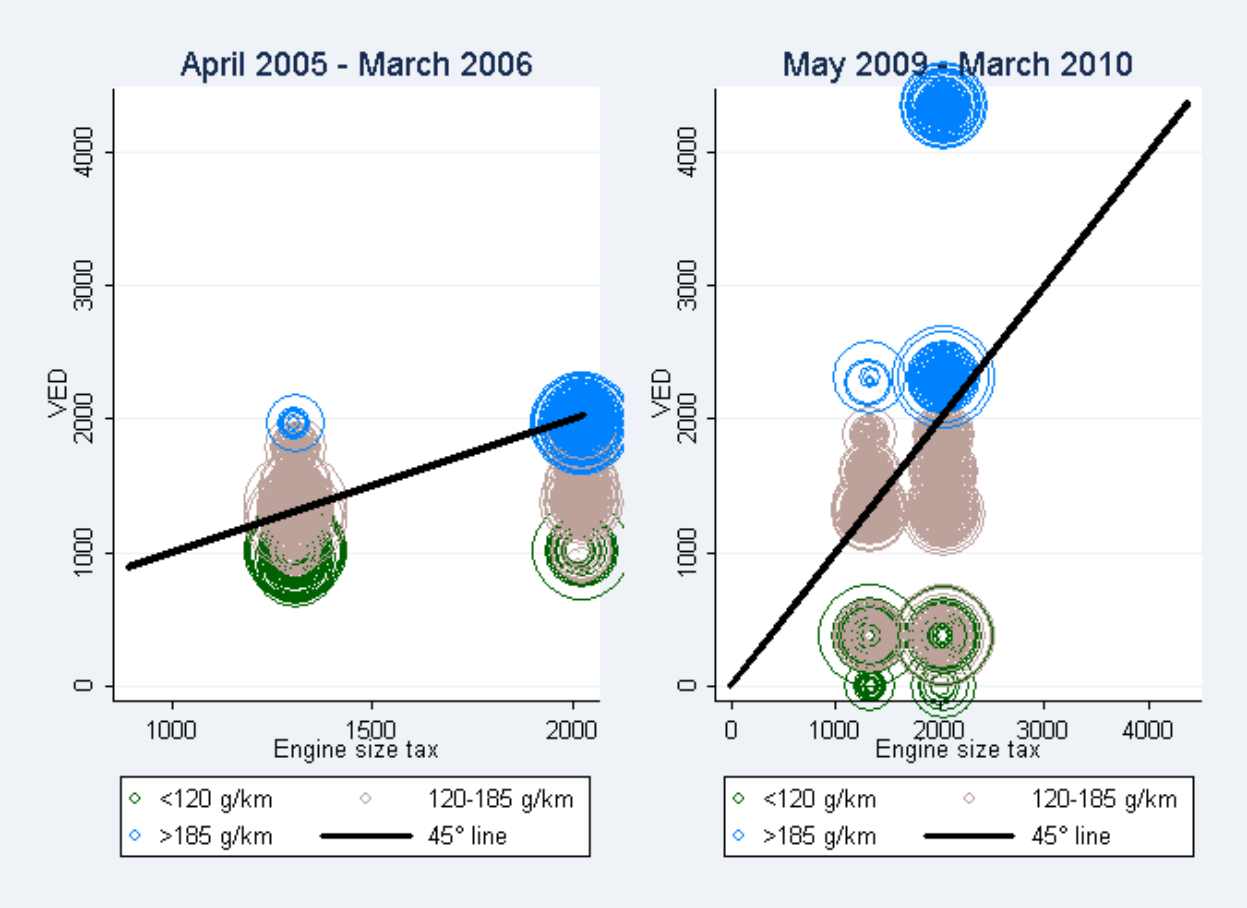
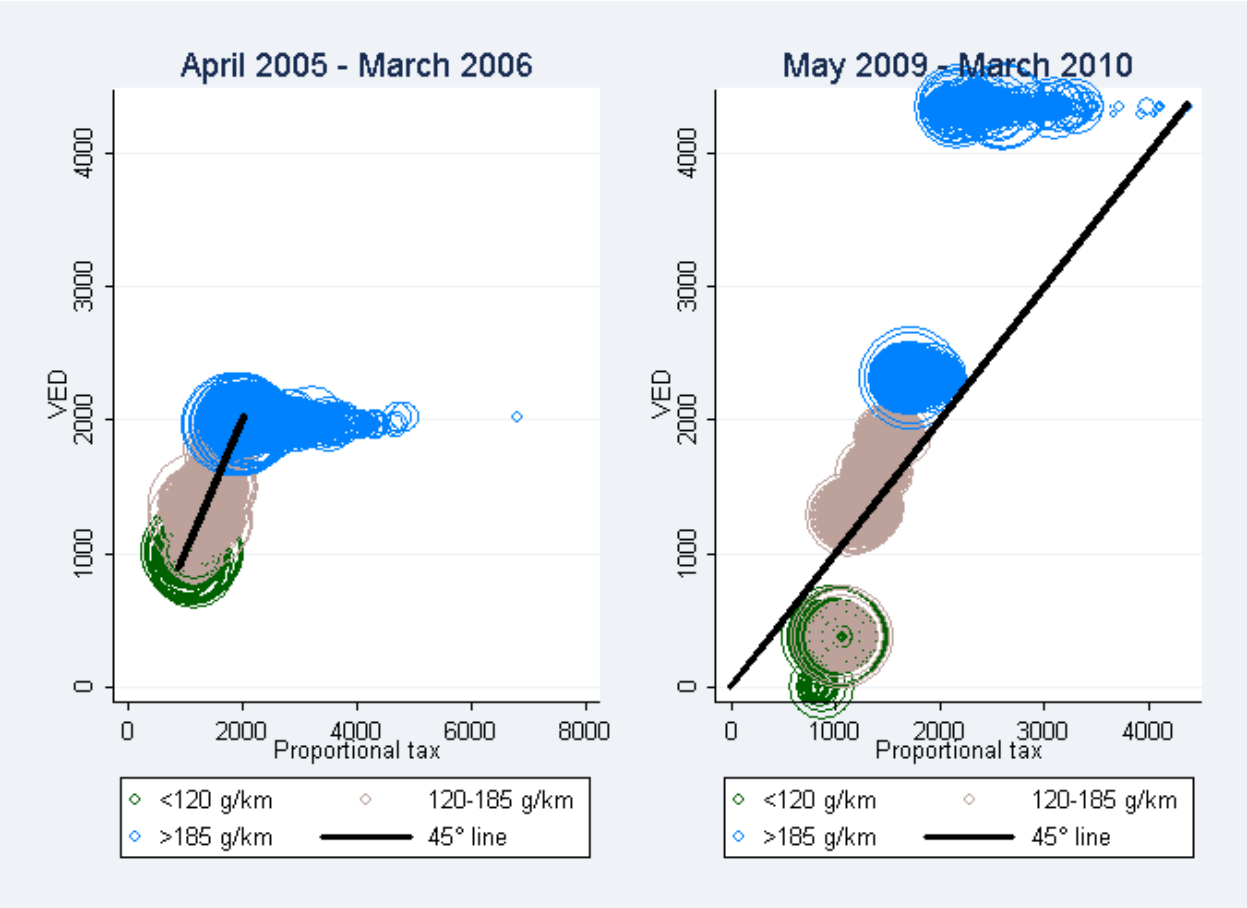


FIGURE 3. TOTAL TAX PAYMENT UNDER VED AND ENGINE SIZE–BASED TAX



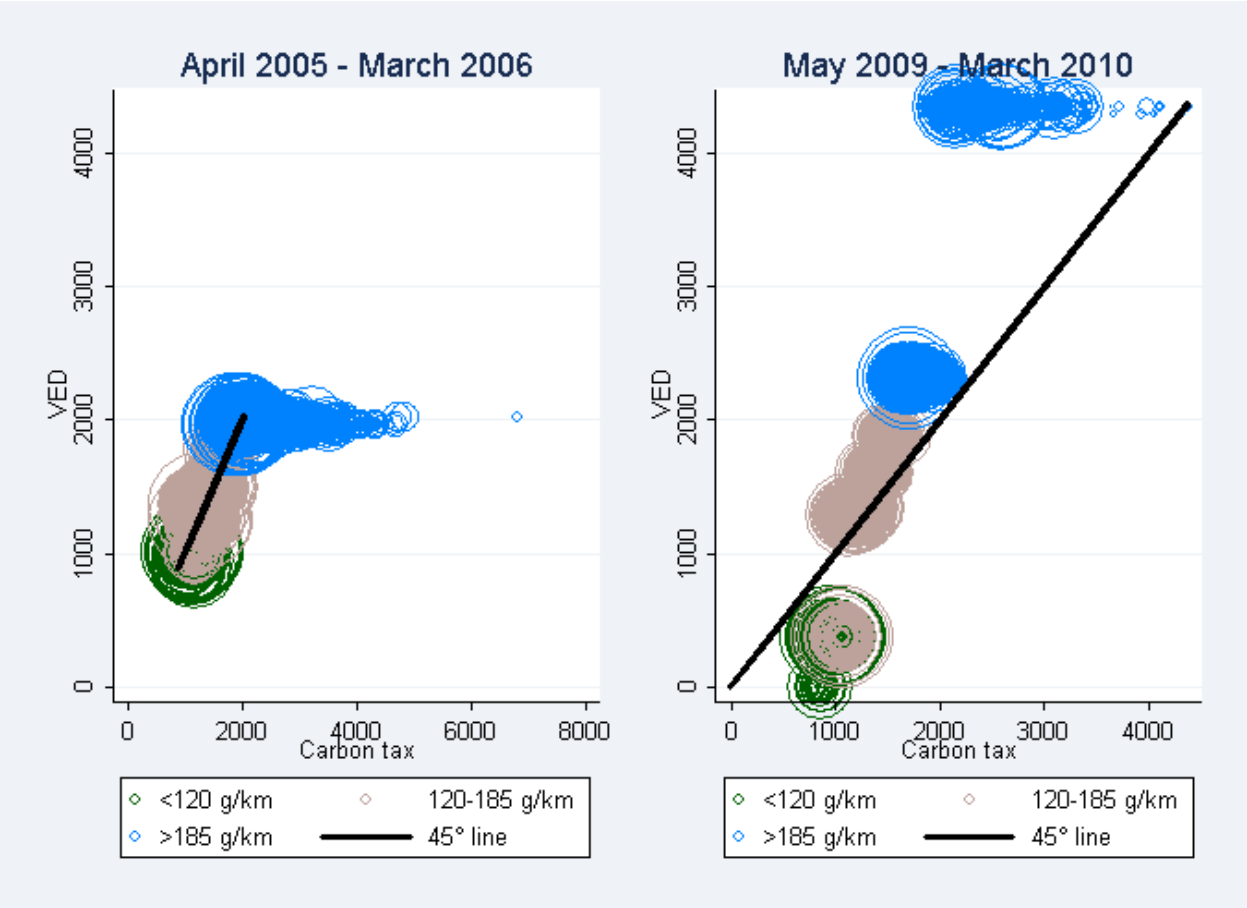
Note: Each circle represents a given make-model-trim variant in the same period. The size of the circle represents new registrations.

FIGURE 4. TOTAL TAX PAYMENT UNDER VED AND PROPORTIONAL TAX



Note: Each circle represents a given make-model-trim variant in the same period. The size of the circle represents new registrations. The proportional tax rate is £0.83 per g/km of CO_2.

FIGURE 5. TOTAL TAX PAYMENT UNDER VED AND CARBON TAX



Note: Each circle represents a given make-model-trim variant in the same period. The size of the circle represents new registrations. The carbon tax rate is £63.0 per ton CO_2.