Fiscal policy and CO_2 emissions of new passenger cars in the EU

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Abstract

To what extent have national fiscal policies contributed to the decarbonisation of newly sold passenger cars? We construct a simple model that generates predictions regarding the effect of fiscal policies on average CO_2 emissions of new cars, and then test the model empirically. Our empirical strategy combines a diverse series of data. First, we use a large database of vehicle-specific taxes in 15 EU countries over 2001-2010 to construct a measure for the vehicle registration and annual road tax levels, and separately, for the CO_2 sensitivity of these taxes. We find that for many countries the fiscal policies have become more sensitive to CO_2 emissions of new cars. We then use these constructed measures to estimate the effect of fiscal policies on the CO_2 emissions of the new car fleet. The increased CO_2-sensitivity of *registration taxes* have reduced the CO_2 emission intensity of the average new car by 1,3 percent, partly through an induced increase of the share of diesel-fuelled cars by 6,5 percentage points. Higher *fuel taxes* lead to the purchase of more fuel efficient cars, but higher *annual road taxes* have no or an adverse effect.

JEL Classification Numbers: H30, L62, Q48, Q54, Q58, R48

Key Words: vehicle registration taxes, fuel taxes, CO2 emissions

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1 Introduction

Transport accounts for about 23% of energy-related CO_2 emissions (Sims and Schaeffer, 2014), that is 15% of global greenhouse gas emissions (Blanco, Gerlagh and Suh, 2014). Within the EU, passenger cars represent about 12% of EU CO_2 emissions.[2] In 1995, the European Commission launched a strategy to reduce carbon dioxide emission intensity (i.e. emissions per kilometer) for new cars sold in the European Union. Since then, the emission intensity of new sold cars has come down remarkably, especially since 2007 (Figure 1). In 2011, the strategy was updated with a proposal to reduce EU transport greenhouse gas emissions by 60%, by 2050 as compared to 1990 levels (European Commission, 2011).

The strategy is based on three pillars. The first pillar targets car manufacturers, requiring them to reduce the average emissions of new cars. The associated directive, established in 2009, aims to decrease the average emissions of new sold cars to 130 gCO_2/km by 2015, and 95 gCO_2/km by 2020 (European Parliament and Council, 2009).[3] The second pillar aims to ensure that the fuel-efficiency information of new passenger cars offered for sale or lease in the EU is made available to consumers to facilitate an informed choice. The third pillar aims to influence consumer's vehicle purchase choices by increasing taxes on fuel-inefficient cars relative to fuel-efficient cars. For our analysis, tax instruments are divided in three categories related to the purchase, ownership and use of a car: the registration tax, the annual road tax and annual income tax for company cars, and the fuel tax.[4]

The three pillars are expected to reinforce each other. Increasing the tax burden on fuel-intensive cars, relative to the burden on fuel-efficient cars (third pillar), and providing information (second pillar) is expected to increase the sale of fuel-efficient cars, which in turn makes it more profitable for car manufacturers to produce fuel efficient cars (the first

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[2] http://ec.europe.eu/clima/policies/transport/vehicles/cars/index_en.htm

[3] All data on CO_2 emission/km in this study are determined according to the NEDC guidelines (New European Driving Cycle, the prescribed European test cycle).

[4] We use purchase tax, registration tax, and acquisition tax interchangeably. Similarly, road taxes and annual taxes refer to the same fiscal instrument. Due to a lack of data, we did not include annual income tax for company cars in our analysis. See Section 7.

pillar). Our study assesses the effectiveness of the third pillar. We construct measures for the level and CO_2 sensitivity of car taxes so that we can compare different tax regimes over countries and years, and we then use these constructed measures to evaluate the effects of these taxes. Figure 2 presents the EU15-average for two of our constructed variables, showing the implementation of the third pillar policy; the figure presents the average CO_2 sensitivity of registration taxes in the EU15 for petrol and diesel cars. We elaborate on the construction of this variable in Section 3.2. On the vertical axis, we plot the increase in the registration tax in Euros, for each increase in CO_2 emission intensity (gCO_2/km), if all other car features remain constant. The figure shows that an increase of the emissions intensity by 10g CO_2/km implies, on average, an increase in the registration tax of about €130 in 2001, and €350 in 2010.[5]

Taxes, including car taxes, are decided on a national level, though. In 2005, the European Commission proposed to harmonise national vehicle registration and annual road taxes (European Commission, 2005), but the proposal was rejected by the member states. Yet, over the years, many EU-countries implemented the third strategy pillar, greening the car taxes though either a revision of purchase taxes, company car taxes or annual road taxes. Figure 3 shows the emissions intensity of petrol cars in the EU15 countries (EEA 2013, Eurostat 2014), and thus presents the effect of changing policies and changes in other variables. Newly sold passenger cars in the different EU15 countries have quite different levels of CO_2-emissions, but there is a robust downward trend, again especially since 2007.[6] In 2010, average emissions from new cars ranged from 130 gCO_2/km (Portugal) to 153 (Germany).[7] Since then, emissions have continued to decrease.

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[5] All prices are deflated with 2010 as base year. For comparison, note that the EU from 2019 will levy a penalty of €95 per gCO_2/km if the average CO_2 emissions of a manufacturer's fleet exceed its limit value.

[6] The anticipation of regulation EC/443/2009 (European Parliament and Council, 2009) is a possible explanation for the downward trend after 2007.

[7] We did not use so-called 'super credits' to calculate average emissions (according to EU-regulation 443/2009, super credits only apply as of 2012)
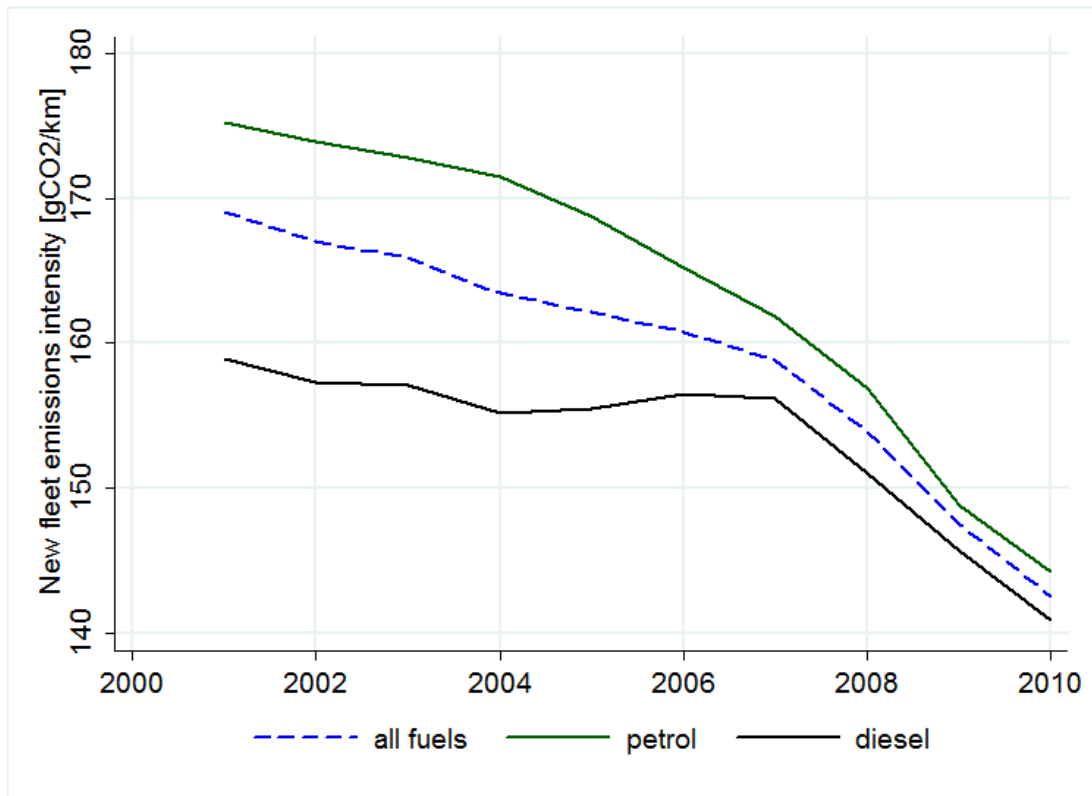
Figure 1: CO$_2$ emission-intensity for new cars, EU15 average[8] (Source: Campestrini and Mock, 2011)

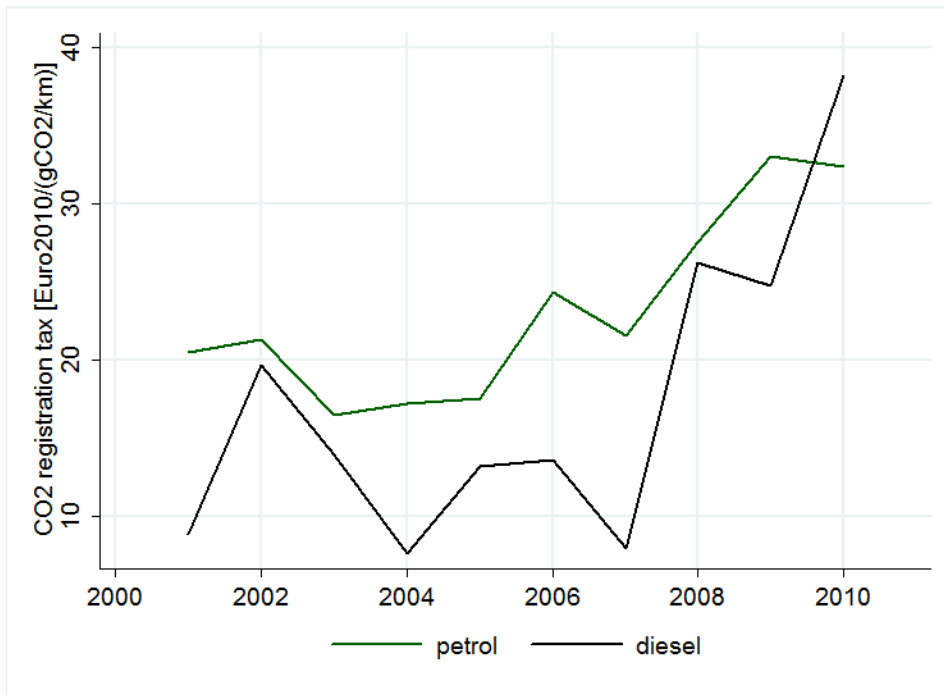[8] The figures averages over 15 countries without weights.

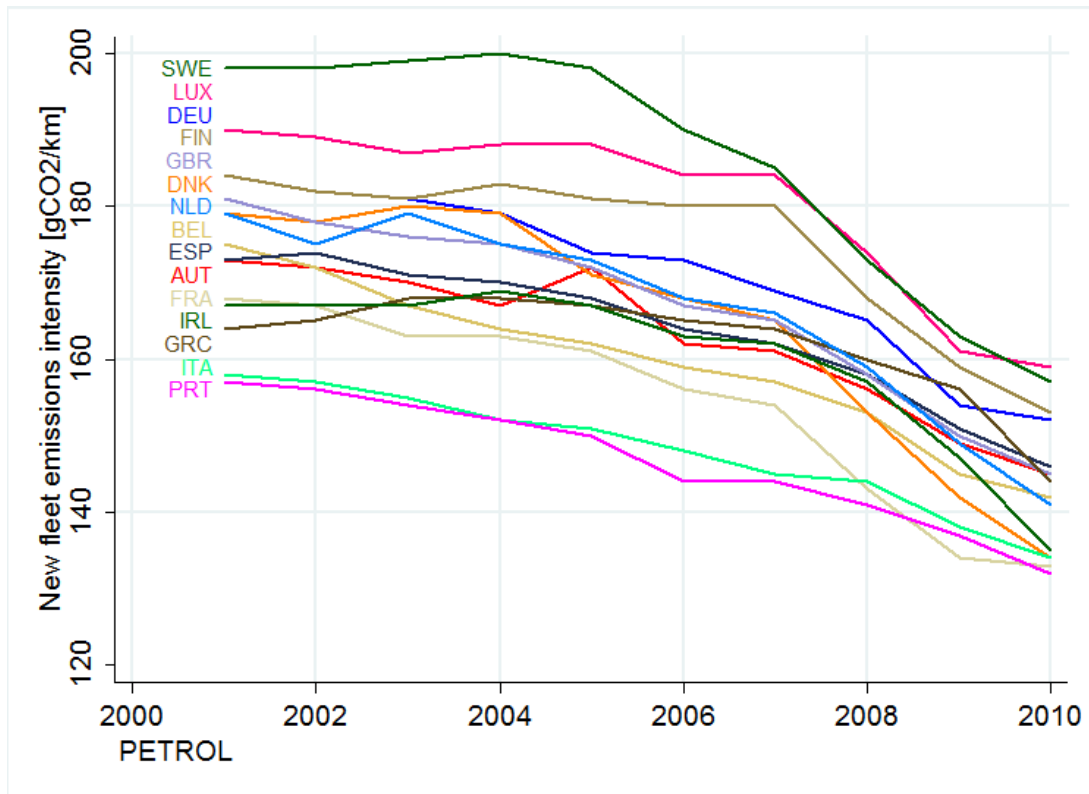Figure 2: CO_2 sensitivity of registration taxes averaged over EU15[9]

Figure 3: CO$_2$ emission-intensity for new petrol cars, by country (Source: Campestrini and Mock, 2011)

The figure also shows substantial differences across countries. CO$_2$ emissions of new cars have declined most rapidly in Sweden and Denmark. There are various possible explanations for the differences between countries, and changes over time in the fuel efficiency. For example, the fall in Sweden's emission intensity in Figure 3 may be attributed to domestic policies (Huse and Lucinda, 2013), or to convergence to the EU average, whereas Denmark's move from being average to becoming one of the most fuel-efficient countries might be the consequence of its aggressive car tax policies. Overall, we can sort these explanations into five categories. The first category relates to the EU's first pillar, which requires manufacturers to sell more fuel efficient cars. For this reason, the portfolio of cars available for purchase is expected to become more fuel-efficient over time. Second, the type of cars bought and their fuel efficiency may partly be explained by trends in consumer preferences. The EU second pillar is related to this cateogory. Third is fiscal policy on registration and road taxes, related to the third pillar. Countries have developed widely different fiscal policies aimed at promoting fuel-efficient cars. Some countries have

much more aggressive policies vis-a-vis other countries, and countries moving in the same direction still implemented their policies in different years. Fourth are fuel taxes, which differ substantially between countries, and many countries have seen changes in fuel taxes. Fifth are income and the economic crisis. Higher incomes are associated with larger cars, and lower incomes with smaller, more fuel-efficient cars. In addition, the economic crisis hit the countries very differently. Those countries hit hardest by the crisis are expected to see – all else equal – the largest drop.

In this paper, we focus on the third cause, associated with the third pillar. That is, we address the following research question: to what extent have national fiscal policies contributed to the decarbonisation of newly sold passenger cars? We construct a simple model of a representative agent to generate predictions regarding the effect of fiscal policies on average CO_2 emissions of new cars. We study changes at the aggregate level and are interested in differences between countries and changes over time within countries. That is, the model and our econometric analysis do not provide a detailed micro foundation of consumers' decisions; see Berry et al. (1995) or Meerkerk et al. (2014) for such an analysis. After presenting the model, we build a dataset in which we compare vehicle tax systems across 15 countries over the years 2001-2010. We use a dataset of vehicle-specific taxes, and use these data to characterize each country's tax system at year t with regards to the average registration and road tax, and the sensitivity of the taxes with respect to the car CO_2 emissions. We differentiate taxes by petrol and diesel, so that we construct 8 variables to provide an elaborate characterization of a country's vehicle tax system for a given year. Both the construction of the multiple tax proxies and the multi-country sample mark important contributions to the empirical literature, which typically has considered a single-country single-event (Hennesy and Tol 2011, Huse and Lucinda 2013, Ciccone 2014, D'Haultfoeuille et al. 2014, Cropper and Chugh 2014).

The constructed variable are used to empirically study the effect of the fiscal treatment, especially the car purchase tax, on the fuel efficiency of newly sold cars. We identify the effect by considering dynamic differences between countries in car taxes and in emission intensities. We control for static differences between countries through country fixed effects, control for income and for common dynamic patters (e.g. EU policies) through time fixed effects. We can identify the effect of fiscal policies on car sales as some countries have consistent low purchase taxes (<30%) that are not very sensitivity to CO_2 emissions (Belgium, France, Germany, Italy, Luxembourg, Sweden, United Kingdom), while

Spain has low purchase taxes but these have become substantially more CO_2 sensitive over the period 2001-2010. Greece has high purchase taxes (>30%) but these became less CO_2 sensitive over the years, and the remaining countries (Austria, Denmark, Finland, Ireland, Netherlands, Portugal) have relatively high purchase taxes (>30%), with a CO_2 component that substantially increased over the years (>10 €/(gCO_2/km)), though the countries differ substantially. Our empirical strategy is based on the correlation between the uneven developments in taxes and patterns in the emission intensities for these countries.

2 Literature

There is an emerging empirical literature on the effects of fiscal policies on the fuel-efficiency of newly sold cars. The general finding is that fiscal policies are an effective tool to influence car purchase decisions. In addition, the literature establishes that purchase taxes are more effective than annual (road) taxes, and that tax reform can cause sizable petrol-diesel substitution.

A strong example of the responsiveness of car purchases to fiscal policies is provided by D'Haultfoeuille et al. (2014). They assess the effect of the system of fees and rebates that existed in France from December 2007 to December 2009. In this system, owners of fuel efficient cars could receive a tax rebate of up to 1000 euros whereas fuel inefficient car owners had to pay a fee of up to 2600 euros. The precise rebate and fee thresholds showed up remarkably in the sales for different car types, with large sales increases just below and drops just above the thresholds.

The effectiveness of car taxes can depend on the subtle features of the policy adopted. The theory of rational choice for car purchases assumes that consumers fully internalize both the expected cost in terms of annual road and fuel taxes, as well as purchases taxes. Empirical evidence however suggests bounded rationality. Consumers do not exploit all available information equally, and tend to give more weight to short-term costs and benefits, known as "consumer myopia" or nearsightedness (DellaVigna, 2009). For example, when deciding on whether to purchase a more fuel efficient car, consumers tend to calculate the expected savings in fuel costs only for about three years (see Greene et al., 2005; Kilian and Sims, 2006; Greene et al., 2013). This nearsightedness is considered a main reason why, compared to annual taxes, vehicle acquisition taxes are more effective in directing consumers' buying decisions (Brand et al., 2013; Gallagher and Muehlegger, 2011; Klier and Linn, 2012; van Meerkerk et al., 2014).

Another phenomenon identified by the literature is the substitution between petrol and diesel cars. When Ireland differentiated its purchase and annual road taxes according to CO_2 emission intensities, sales of smaller cars did not go up. Instead, sales of diesel cars increased at the expense of large petrol cars (Hennesy and Tol, 2011, Leinert et al., 2013). This unanticipated shift towards diesel cars reduced the average CO_2 emissions by 13 percent in the first year after the tax reform (Rogan et al., 2011). Less advantageous, it also raised NO_x emissions (Leinert et al., 2013). The vehicle acquisition tax reform in Norway in 2007 resulted in a drop in CO_2 emissions of newly sold cars by 6 gCO_2/km in the short run, mainly caused by an increase of diesel market share by almost 23 percentage points (Ciccone, 2014). The tax reform in Denmark in 2007 contributed to the sales of more fuel-efficient cars in the years thereafter. Yet, Mabit (2014) argues that the biggest contribution to the sales of fuel-efficient cars is probably not the tax reform, but technological improvements.

All research discussed above analyses the effect of specific vehicle tax policies in a single country. Hence, these papers cannot control for year-specific effects and the results are not easily generalizable. Our empirical analysis does not consider a single-event in one country, yet studies more broadly the fiscal treatment of car purchases and ownership in relation to car emissions. There are some previous cross-country and panel-data studies on the effect of fuel prices on fuel efficiency (Burke and Nishitateno 2013, Klier and Linn 2013). The effect of the registration and road tax level on car purchases is previously studied in Ryan et al. (2009), who use a panel structure for EU countries. They conclude that vehicle taxes, notably registration taxes, are likely to have significantly contributed to reducing CO_2 emission intensities of new passenger cars. Ryan et al. (2009) focus on the average level of registration taxes in a country.[10] We take this analysis one step further by constructing measures of the CO_2 sensitivity in addition to the level of registration and road taxes. This allows us to exploit differences between EU countries in the stringency and timing of climate-related vehicle fiscal policies. An important part of our study is thus a

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[10] Note that Ryan et al. (2009) weigh the registration tax measure by vehicle sales, so that in their analysis the right-hand-side variable depends on policy outcomes. To prevent dependency of right-hand variables on policy outcomes, we construct tax measures that do not use sales for weighing; see footnote 13.

more comprehensive characterization of the vehicle tax system that can be used to compare differences across countries and changes over time, based on a large dataset of country-year-vehicle specific prices inclusive and exclusive of taxes.

3 Model

We illustrate the effect of vehicle purchase taxes on the average emission intensity with a simple model. We consider two car types. A representative consumer maximises (expected future) utility u dependent on the current purchase of cars, q_1 and q_2, and income m net of purchase expenditures x:

$$\max_{q_1,q_2} u(q_1, q_2, m - x) \text{ s.t. } s.t. p_1^c q_1 + p_2^c q_2 = x. \tag{1}$$

where p_i^c are costs per quantity, including registration taxes as well as future variable costs and annual taxes. The utility function satisfies the standard assumptions on continuity, differentiability, positive derivatives, and concavity. We also assume that both types are normal goods (increasing consumption with increasing income, decreasing consumption with increasing prices) and that the total budget for cars, x, increases in total income, m.

We do not model consumers' care about the environmental performance of cars as such (see Achtnicht 2012 for an analysis along those lines), but focus on the effects of government instruments geared to direct consumers' choices. We assume that the tax is fully shifted to consumers,[11] so that the consumer price of cars is

$$p_i^c = (1 + \tau_i)p_i^p, \tag{2}$$

where τ_i is a type-specific ad valorem tax and p_i^p is the producer price.

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[11] We abstract here from strategic pricing by car manufacturers. Though this is important as a mechanism, our results below will hold as long as the car manufacturers pass-through part of taxes. In general, ad valorem taxes may be under- or overshifted under Bertrand competition with differentiated products (Anderson, De Palma and Kreider, 2001). If car manufacturers differentiate prices between countries so as to partly compensate taxes, the effect of fiscal measures will be reduced, and our coefficients will become smaller and less significant.

The tax τ_i consists of a uniform component φ and an environmental component, where θ is a relative weight of the environmental component. The two car types have different emission intensity, say grams of CO_2 per km, which we denote by β_i. Without loss of generality, let $\beta_2 > \beta_1$, for example because car type 2 is more spacious, has more weight, or is more fancy. The type-specific tax becomes:

$$\tau_i = \varphi + \theta\beta_i. \tag{3}$$

We are interested in the effect of changes in car taxes on the average CO_2 intensity of the car fleet, which we define as

$$B = \frac{\beta_1 q_1 + \beta_2 q_2}{q_1 + q_2}. \tag{4}$$

Policy can change the uniform component of the car tax, φ, the environmental component, θ, or both. We define the average car-tax, given by

$$T = \frac{\tau_1 q_1 + \tau_2 q_2}{q_1 + q_2} = \varphi + \theta B. \tag{5}$$

so that we can study shifts in the tax structure while keeping a constant overall tax rate. It is intuitive that an increase in the weight of car-feature θ, while keeping the average tax rate T constant, will decrease the average emission-intensity of the cars.

Proposition 1. An increase in the weight of environmental performance in taxes, θ, while keeping average total taxes T constant, will decrease the average CO_2 intensity B:

$$\frac{dB}{d\theta} < 0. \tag{6}$$

Proof. The policy in the proposition increases the price of the relatively emission-intensive car and decreases the price of the more fuel-efficient car. The result follows immediately from the assumption that both car types are normal goods. Q.E.D.

Thus tilting the car taxes to become more CO_2-dependent will make the car fleet more CO_2-efficient. The effect of an overall car tax increase depends on the comparative income elasticity of the two car types.

Proposition 2. If the environmental tax component θ is sufficiently small, then feature B decreases with an overall tax increase φ (or equivalently an increase in T) if and only if the less fuel-efficient car type has higher income elasticity:

$$\frac{dB}{d\varphi} < 0 \Leftrightarrow \frac{\partial q_2}{\partial m}\frac{m}{q_2} > \frac{\partial q_1}{\partial m}\frac{m}{q_1}. \tag{7}$$

Proof. Consider $\frac{\partial q_2}{\partial m}\frac{m}{q_2} > \frac{\partial q_1}{\partial m}\frac{m}{q_1} \Leftrightarrow \frac{\partial q_2}{\partial x}\frac{\partial x}{\partial m}\frac{m}{q_2} > \frac{\partial q_1}{\partial x}\frac{\partial x}{\partial m}\frac{m}{q_1} \Leftrightarrow \frac{\partial q_2}{\partial x}\frac{m}{q_2} > \frac{\partial q_1}{\partial x}\frac{m}{q_1} \Leftrightarrow \frac{\partial q_2}{\partial x}\frac{x}{q_2} > \frac{\partial q_1}{\partial x}\frac{x}{q_1}$.

When $\theta = 0$, an increase in φ is equivalent to a decrease in the budget for cars. Because type 2 has a larger income- and budget elasticity $\left(-\frac{\partial q_2}{\partial \varphi}\frac{\varphi}{q_2} > -\frac{\partial q_1}{\partial \varphi}\frac{\varphi}{q_1}\right)$, the average CO_2-intensity B goes down. By continuity, the result also holds for θ sufficiently small. Q.E.D.

The typical hypothesis asserts that demand for luxurious cars is more income-elastic (Mannering and Winston, 1985). Larger cars, which are also emission-intensive, tend to be more comfortable. For example because they offer more storage and lower occupant fatality rates in vehicle-to-vehicle crashes – attributes that are more easily dispensable than a car's basic transportation service. It thus seems plausible that demand for spacious cars will react more strongly to an equiproportional price increase. The proposition then predicts a decrease in the average pollution intensity if the uniform tax φ increases.

For high environmental taxes θ the effect may be reverted, as an increase in the uniform tax rate φ can then represent a fall in the *relative* price of less fuel-efficient cars. As we will see however, the relative importance of the environmental component in total car taxes is modest in European countries, so that the proposition's condition seems to apply.

4   Data

Here we describe the data used for the empirical analysis. The dependent variable of interest is the average CO_2 intensity of newly purchased vehicles, which depends on substitution patterns between more and less fuel efficient cars, but also on common fuel efficiency improvements over all cars, which in our econometric strategy is absorbed by time fixed effects. The main explanatory variables are fuel taxes and the two coefficients used in the model in Section 3: the average level of registration and annual road taxes, and

their CO_2 sensitivity. Here, we define the vehicle registration tax as all one-off taxes paid at the time the vehicle is registered, which is usually the time of acquisition. For road taxes, we include all annual recurrent taxes of vehicle ownership. We construct these data for each country, year and fuel type in our sample using a detailed database with vehicle registration taxes and road taxes at vehicle-country-year level.

4.1 Data sources

Our first data source is a set of manufacturer price tables as supplied by the European Commission (2011a). These tables form an unbalanced panel with 11930 observations on prices and registration taxes, across 204 car types, 20 countries (15 countries up to 2005) over the years 2001-2010. Petrol cars make up about two-third of all observations. This source includes the retail price data per country inclusive and exclusive of the registration tax, and allows us to construct the vehicle-country-year specific registration tax. As of 2011, the European Commission no longer collects data on automobile prices. As these prices are a crucial part of our analysis, our series end in 2010. Next we construct vehicle-country-year specific road taxes using our second data source: the ACEA (2010) tax guides and the European Commission (2011a) passenger car dataset. The construction of the country registration and annual tax dataset is an important extension compared to Ryan et al. (2009), and enables us to differentiate between average taxes and the CO_2 sensitivity of vehicle-related taxes. We also take information on fuel taxes from the ACEA tax guides. Because most cars are petrol or diesel, we restrict our sample to these two fuel types. Sales data play no role in the construction of the country tax data sets.

The next dataset, from Campestrini and Mock (2011), contains information on the CO_2 intensity of the newly purchased diesel and petrol cars (CO_2 emissions in g/km, weighted by sales, see also Figure 1) and the shares of diesel cars (See Figure 6 in the appendix Section 8.3). We have this information for the EU15 countries, from 2001-2010. Lastly, data on nominal per capita GDP is taken from Eurostat (2014). We deflate all prices (sales prices, taxes, GDP) using a common EU15 price deflator.[12]

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[12] The deflator is constructed using a weighted average of the EU15 countries' individual inflation rates, according to standard EU methodology. See https://www.ecb.europa.eu/stats/prices/hicp/html/index.en.html.

4.2 Constructing country average and CO_2 sensitivity of car taxes

Countries have widely divergent rules for registration and road taxes. In some countries, vehicle registration taxes are based on CO_2 emissions, in others, the cylindrical content is used to compute the tax, or the sales price of the car. In many instances, registration taxes combine multiple variables. Rules for annual road taxes vary even more across Europe. Some countries base their annual tax on a car's engine power (in kW or hp), while other countries use cylinder capacity, CO_2 emissions, weight and exhaust emissions. In addition to the dispersion between countries, for both registration and road taxes, many countries have changed their policies over the period 2001-2010; they adopted (temporary) discounts for fuel efficient cars, or additional charges for cars exceeding specified standards. We compare tax systems across countries by characterizing each country's tax system at year t by the two coefficients used in our model in Section 2. The first coefficient describes the country-year average tax, the second the CO_2 sensitivity of the tax. Both variables are computed for both the registration and road tax, and for petrol and diesel. We thus construct 8 variables that characterize a country's vehicle tax system for a given year.

We now provide the details. Let $CO2_{it}$ be the CO_2 intensity of car-type i in year t, τ_{cit} the (registration or road) (percentage) tax in country c, and let δ_{cit} be the index $\{0,1\}$ identifying whether the data are available for country c. For the sake of exposition, we do not use subscripts for fuel and tax type (registration versus road). We construct the country-specific average CO_2 intensity and average tax rate (denoted by bars on top over the variables):[13]

$$\overline{CO2}_{ct} = \frac{\sum_i \delta_{cit} CO2_{it}}{\sum_i \delta_{cit}} \tag{8}$$

$$\bar{\tau}_{ct} = \frac{\sum_i \delta_{cit} \tau_{cit}}{\sum_i \delta_{cit}} \tag{9}$$

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[13] In the construction of our tax system variables we do not weigh by sales, to prevent our description of the tax system from being contaminated by the subsequent effects of that same tax system. The tax system may of course affect sales, and thereby the average CO2 intensity of new cars. This is discussed in Section 6.

That is, the typical car for a country has emissions $\overline{CO2}_{ct}$ and pays a tax rate $\bar{\tau}_{ct}$. We subsequently calculate the CO_2-sensitivity of the tax by comparing how much taxes increase when CO_2 emissions increase, on average, and weighted:

$$CO2TAX_{ct} = \frac{\sum_i w_{cit}(\tau_{cit} - \bar{\tau}_{ct})}{\sum_i w_{cit}(CO2_{cit} - \overline{CO2}_{ct})} \qquad (10)$$

Where weights are given by the deviation from the average CO_2 intensity:

$$w_{cit} = (CO2_{cit} - \overline{CO2}_{ct}) \qquad (11)$$

The squared weights ensure that the denominator in (10) is strictly positive, and that the CO_2 sensitivity is mainly determined by the tax-differences between the fuel-efficient and fuel-intensive cars.

Yet, if we want to determine a country's tax pressure and compare between countries, we should not consider the tax of the typical car for that country, but the tax for a typical car that is the same over all countries. Thus, we construct the (virtual) tax rate that would apply to a car with a CO_2-emission profile $\overline{CO2}_t$ that is typical for the set of all countries:

$$\overline{CO2}_t = \frac{\sum_{c,i} \delta_{cit} CO2_{cit}}{\sum_{c,i} \delta_{cit}} \qquad (12)$$

$$TAX_{ct} = \bar{\tau}_{ct} + CO2TAX_{ct}(\overline{CO2}_t - \overline{CO2}_{ct}) \qquad (13)$$

The above method generates 8 variables for each country-year pair. The precise interpretation depends on the details of the input variables, $CO2_{it}$ and τ_{cit}. If CO_2 emissions are measured linearly in [gCO_2/km], and taxes in euros, then $\bar{\tau}_{ct}$ is the average tax in euros [€] while $CO2TAX_{ct}$ is the increase as measured in [€/(gCO_2/km)]. If taxes are measured *ad valorem*, then $\bar{\tau}_{ct}$ is the average tax rate in percentages while $CO2TAX_{ct}$ is the increase in the tax rate per gCO_2/km. Our preferred specification uses the logarithm of one plus tax *rates* and the logarithm of CO_2 emissions, so that variables are interpretable as elasticities, and (with time fixed effects) the construction is independent of price levels. In this case, a decrease of the variable $CO2_t$ by 0.01 means that emissions have come down by 1%. A decrease of the variable $\bar{\tau}_{ct}$ of 0.01 means that the tax rate for the typical car has fallen by 1%. If two car types are completely identical (including prices at the factory gate), but one

car is 10% more fuel efficient, then the consumer price of the more fuel-efficient car is 0.1*
CO2TAX per cent below the consumer price of the more fuel-intensive car. All estimations
in the main text are based on the double-log variables. We have reproduced our results for
a linear model, which is presented in the appendix, Section 8.2. The appendix also provides
the equations with more elaborate references to the details of taking logarithms.

Figure 4 below shows a typical breakdown of the vehicle registration tax rate in its
level and CO_2 sensitivity. The charts show the registration taxes paid in the Netherlands, in
2001 (left) and 2010 (right), for a series of petrol (upper) and diesel (lower) cars. The dots
are observations for individual car types, described at the beginning of Section 3.1. The
lines present the 'predicted' tax rates based on the two proxy variables *TAX* and *CO2TAX*
constructed above. As is immediately visible from the left and right panels, the tax rate has
become more sensitive to CO_2 emissions between 2001 and 2010, that is, the slope of the
line has increased. Figure 5 shows the decomposition of the tax in its average tax rate and
the CO_2 tax over the years 2000-2011. The average registration tax rate for petrol cars
started at about 50 per cent, and sharply dropped in the last years reaching about 47 per
cent in 2010 and 40 per cent in 2011. The CO_2 sensitivity of registration taxes however has
increased substantially for both petrol and diesel cars between 2000 and 2011. Figure 4
(panel in top-right corner) illustrates this shift. Various tax breaks for fuel-efficient cars
came into force, which substantially increased the CO_2 sensitivity of taxes, from about 10%
to 25% (see Figure 5, right panel), but at the same time reduced the average tax. All other
things equal, in 2011, the after-tax price decreases by about 3% if a car is 10% more fuel-
efficient. The charts in Figure 4 also show that, in the Netherlands, taxes for diesel cars are
persistently above those for petrol cars;[14] in our results section, we will come back to the
effect of tax differentiation between petrol and diesel cars.

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[14] The Netherlands is atypical in the sense that registration taxes and fuel taxes are used as
instruments to segregate the car market. Diesel fuel taxes are low (relative to petrol) while
diesel registration taxes are high (relative to petrol). The tax scheme intends to separate long-
distance drivers (who buy diesel cars) from short-distance drivers (who buy petrol cars).
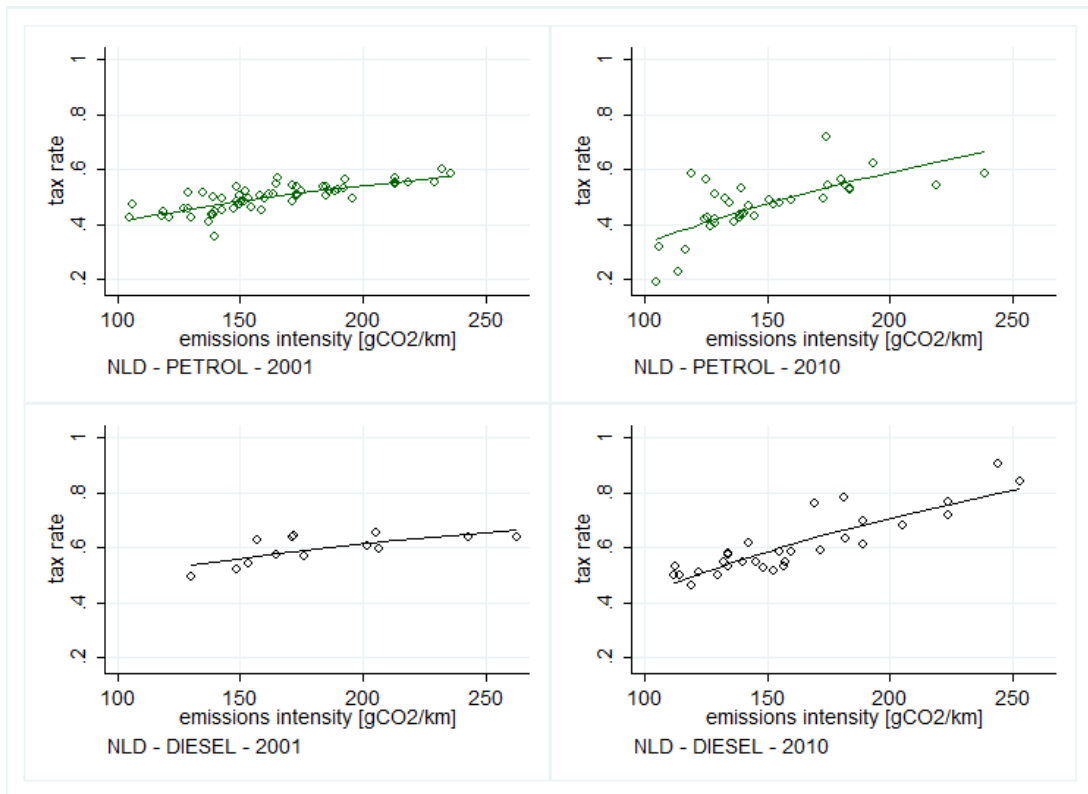
Figure 4: Taxes per vehicle, dependent on CO_2 emission intensity, for the Netherlands, 2001 (left panels) and 2010 (right panels), Petrol (upper) and Diesel (lower). Taxes are measured relative to car prices.
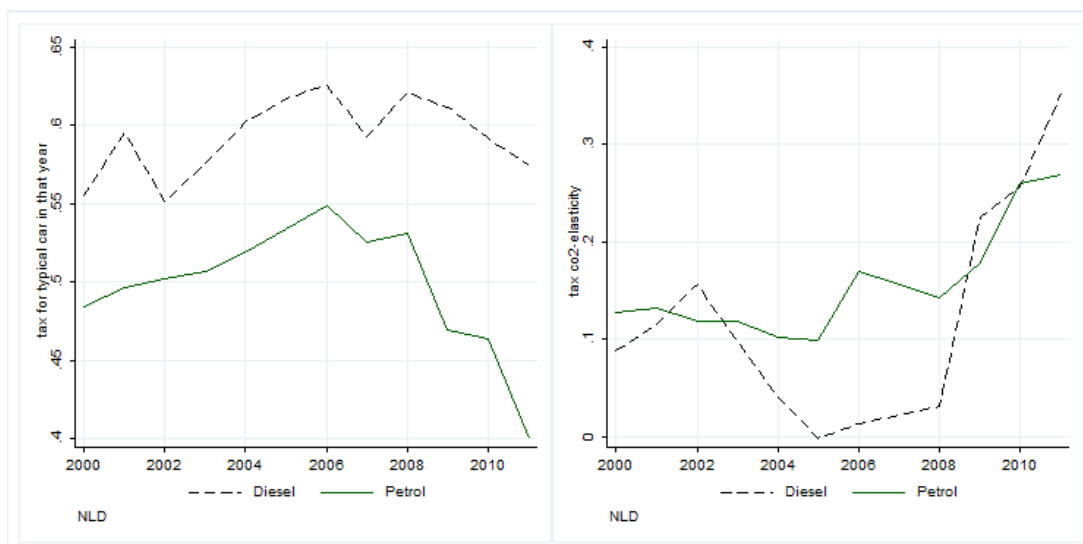
Figure 5: Registration tax levels for typical vehicle, and tax dependence on CO_2 emission intensity, for the Netherlands, 2000-2011, Petrol (green solid) and Diesel (black dashed).[15]

Table 1 below provides some additional summary statistics and the means for the first and last sample years. Over 2001-2010, the average registration tax for diesel cars decreased from 46 to 40 per cent (see footnote at table, and also see Table 5 in the appendix Section 9.2) while for petrol cars the registration tax rate decreased from an average of 39 to 35 percent. The extra tax paid for purchasing a high-emission vehicle has increased substantially, however. In 2001, purchasing a diesel vehicle with 10 percent higher emissions increased the registration tax rate by approximately 0.6 percentage point on average. By 2010, this has increased to 1.4 percentage point. For some countries, the elasticity of the registration tax rate with respect to emissions is negative. This does not directly imply that fewer taxes are paid for polluting vehicles. If a more polluting car is more expensive, then the absolute tax paid can increase while the tax rate paid can decrease.[16]

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[15] Note that the figure extends the period (2001-2010) over which we run the regressions. Also note that the y-axis on the left panel should be interpreted as 'elasticity': $\ln(1+\tau)$. Thus, a value of 0.5 implies a tax of $\exp(0.5) = 65$ per cent.

[16] This can happen if part of the registration tax is independent of the car price. Indeed, results from the linear model presented in the appendix, Table 5, show that in all countries, tax *levels* (weakly) increase for more CO_2 emission-intensive vehicles.

In 2001, the road tax rate is on average 2 percent of the vehicle's (tax-exclusive) purchase price, for both diesel and petrol cars. Several countries have no annual road tax. The average elasticity of the annual tax rate with respect to CO_2 emissions has changed from being negative in 2001 to a positive value in 2010. Overall, there is a slight pattern towards lower road tax rates, combined with a greater dependence of the tax rate on the emissions of a car.

Table 1: Summary statistics for constructed tax levels and CO_2 sensitivity for EU15[*]

		2001-2010				2001	2010
		Mean	Std. dev.	Min	Max	mean	mean
Vehicle registration tax rate	Diesel	0.35	0.26	0.16	1.12	0.38	0.34
	Petrol	0.33	0.23	0.14	0.98	0.33	0.30
Vehicle registration tax rate, CO_2 sensitivity	Diesel	0.07	0.19	-0.11	0.66	0.06	0.14
	Petrol	0.10	0.14	-0.02	0.43	0.10	0.13
Road tax rate	Diesel	0.02	0.02	0	0.06	0.02	0.02
	Petrol	0.02	0.02	0	0.08	0.02	0.02
Road tax rate, CO_2 sensitivity	Diesel	-0.004	0.02	-0.07	0.003	-0.015	0.003
	Petrol	-0.004	0.03	-0.09	0.02	-0.011	0.004

[*]All numbers are based on a logarithmic representation. The average tax rate for diesel cars in 2001 was thus exp(0.38)–1=0.46. See Table 5 in the appendix, Section 8.2, for the tax levels and CO2 sensitivity based on the linear model.

Vehicle fiscal measures are correlated, also when we take out country and time fixed effects. Petrol and diesel registration taxes move in tandem, both for the levels and CO_2-sensitivity. The same applies to the annual taxes, where correlations exceed 80%.[17] Petrol and diesel fuel taxes are also positively correlated. The year fixed effects separate fuel price developments from fuel tax changes. There is almost no correlation between the three groups of tax instruments. For annual taxes, we see a very strong negative correlation between the level of annual taxes and its CO_2 sensitivity, implying that the set of annual taxes are strongly multi-collinear, so that we must be careful when interpreting individual coefficients for annual taxes.[18]

[17] See Table 7 in the appendix for details

[18] The negative correlation between the level of annual taxes and its CO_2 sensitivity is 'natural' in the following sense. If the level of annual taxes increase, typically they increase less then

5 Econometric strategy

The benchmark model estimates the dependence of the CO_2 intensity of the new car fleet in country c in year t (as in Figure 3), separately for diesel and petrol,[19] on the two dimensions of the registration car taxes: its level and its CO_2 sensitivity

$$CO2int_{ct} = \alpha_{1c} + \alpha_{2t} + \beta_1 TAX_{ct} + \beta_2 CO2TAX_{ct} + \sum_k \pi_k Z_{ckt} + \varepsilon_{cit}, \qquad (14)$$

where α_{1c} and α_{2t} are country and time dummies, and the country-time specific control variables Z include income, the share of diesel cars in total sales, and gasoline taxes.[20] For our preferred logarithmic model, we use logarithms for the dependent variable. In the linear model (see appendix, Section 8.2), the dependent variable is measured in average grams of CO_2 emissions per km.

We add convergence patterns through the control variable, through

$$Z_{c1t} = CO2int_{c0} \qquad (15)$$

$$Z_{c2t} = (year_t - 2001) \times CO2int_{c0}, \qquad (16)$$

where $CO2int_{c0}$ is the CO_2 intensity of the new fleet in the base year 2001. Convergence between countries is measured through a negative coefficient for the interaction term (16). We assume there is no systematic correlation between observed fiscal vehicle policies and unobserved policies such as vehicle retirement plans that could induce omitted variable bias.

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proportional with the car's size, weight and price. Thus, annual taxes have a tendency to be regressive. This is picked up by a negative coefficient for the CO_2 sensitivity.

[19] All variables are specific for diesel and petrol. We use both petrol and diesel independent variables when we estimate the diesel share as dependent on car taxes.

[20] The fuel tax is estimated for each country-year-fuel type by fuel: tax=ln(1+{fuel tax level}/{fuel price}), where we take the fuel price as the average fuel price across the countries.

We estimate the model for both fuel types jointly and separately, with and without the annual taxes. One of the control variables, the share of diesel cars, is itself dependent on a country's tax regime. As discussed in the introduction, diesel cars are typically less CO_2 intensive than petrol cars, and a high CO_2 intensity of taxes may thus encourage individuals to switch to diesel cars. To assess whether this affects our results, we re-estimate the model without the diesel share.

6   Results

The main results are presented in Tables 2 and 3. Table 2 displays the results for the CO_2 intensity for diesel and petrol cars respectively. Table 3 then reports the results for the CO_2 intensity of all new purchased cars where petrol and diesel are aggregated, and reports the dependence of the share of diesel cars on taxes.

6.1   Fuel-type specific effects

Starting with the CO_2 intensity of new diesel cars, we find a clear significant effect of registration taxes on CO_2 emissions (see Table 2). Especially the CO_2 sensitivity is an effective instrument to change the characteristics of newly bought vehicles: a 1% increase in CO_2 sensitivity reduces the CO_2 intensity by 0.04 to 0.1 percent. The effect is weaker when we control for the diesel share, suggesting that part of the effect goes through the changes in the diesel share. As we see in Table 3, a higher CO_2 sensitivity of diesel registration taxes increases the share of diesel cars. Buyers who decide to acquire a diesel car as a substitute for a petrol car typically buy diesel cars that are smaller compared to the average diesel car, while they substitute away from petrol cars that are larger compared to the average petrol car (see the case study of Ireland, Rogan et al., 2011, Hennessy and Tol, 2011, Leinert et al., 2013). These consumers who substitute diesel cars for petrol cars thereby reduce the average emissions from both diesel and petrol cars. The mechanism is confirmed by the negative coefficients for diesel share in the diesel emissions (Table 2, columns 1 and 3) and in the petrol emissions (Table 2, columns 5 and 7). Indeed, a closer look at our data (not shown here) shows that diesel cars are on average 20 percent heavier compared to petrol and the average weight for both diesel and petrol cars decreases with an increase in the diesel share. Part of the emission reduction of new cars in the EU has been achieved by lower registration taxes for diesel cars (Table 1 and Appendix, Table 5), which translated in an increased share of diesel cars (Table 3, column 5 and Appendix,

Figure 6), which are typically more fuel efficient than petrol cars (Figure 1), and thus in turn decreases the CO_2 intensity of the average car (Table 3, column 1).

The registration tax level reduces the CO_2 intensity of new diesel cars, yet only significantly so when we account for the diesel share. In response to the observed decline of diesel registration tax levels during the sample period, consumers of small diesel cars switch to relatively less fuel-efficient, heavier diesel models, but there is also substitution from petrol cars to small diesel cars. We find no significant effect for road taxes on the emissions by diesel cars. Higher diesel fuel tax rates increase the fuel efficiency of newly acquired vehicles, as expected (Burke and Nishitateno, 2013). In addition, we find higher CO_2 intensities with increasing income and a clear convergence pattern between EU countries.

We find a similar pattern for petrol vehicles. The effect of CO_2 tax sensitivity is negative and significant: the average CO_2 sensitivity in 2010 (0.13) reduces the CO_2 intensity of new bought cars by about 2 percent. Again, the effect is weaker if we account for the share of diesel cars. Higher taxes for fuel-intensive petrol cars will push potential owners of large petrol cars to consider a diesel car as a substitute, thereby reducing the size and emission-intensity of the average petrol car through the diesel-share variable. An increase in the registration tax level reduces the CO_2 intensity of newly acquired vehicles, but the coefficients are insignificant. For petrol vehicles, annual road taxes receive a significant coefficient, yet the signs are opposite to what is expected. Fuel taxes do not show a significant effect for petrol car purchases.[21]

This paper is one of the first including annual road taxes, in addition to registration and fuel taxes, in the analysis of car purchase behaviour. We find that an increase in the annual road tax level and CO_2 sensitivity *increases* the CO_2 intensity of new petrol cars. We are not sure what causes this finding. It is not obvious that individuals account for future annual tax expenses, as discussed in Section 2. In our regressions, even though the annual tax rates enter significantly, excluding them from the regression has only little effect on the coefficient for the other variables. Hence, we can interpret the other coefficients with

[21] The insignificance is not driven by lack of variation as petrol taxes show up significantly in Table 3.

22

confidence, and conclude that leaving annual taxes unaccounted for probably does not greatly alter our conclusions.

6.2   Aggregate effects

Then consider the overall effect of car taxes on the new fleet emission intensity (Table 3). The diesel share is the most important mediating variable: none of the policy variables is significant when this share is included in the regression, though the joint effect of more CO_2-sensitive diesel and petrol taxes is significantly different from zero (columns 1 and 2).[22] The results in Table 3 allow us to assess the effect of the changes in registration taxes on the diesel intensity. We subtract the log of taxes in 2001 from those in 2010 (Table 1) and multiply the differences with the coefficients in Table 3 (column 5). We conclude that the changes in registration taxes have increased the diesel share by 6.5 percentage points. Using a similar calculation (but using column 2 from Table 3), we find that the changes in registration taxes have reduced the CO_2 intensity of the average new car by 1.3%[23]. 0.9 percentage points of this overall effect is explained by changes in the diesel share.[24] The overall effects are modest; an explanation is that the large countries with a major domestic car industry (France, Germany, Italy, United Kingdom), have relatively low registration taxes that are almost independent of emission intensities.

When leaving out the diesel share, the diesel registration taxes stand out as the most important determinants. Lower overall taxes for diesel cars increase the share of diesel cars and thereby decrease average overall emissions, but also encourage existing diesel drivers to switch to more polluting models. At the same time, a more CO_2 sensitive diesel registration tax favours small diesel cars, increasing the diesel share (column 5 and

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[22] As noted previously and presented in Table 7 in the appendix, policy measures for petrol and diesel vehicles are strongly correlated. This inflates the standard errors of the individual regressors in Table 3, columns 1-4. When testing, we find in column 1 and 2 that the sum of the diesel and petrol coefficients for the CO_2 sensitivity of registration taxes is significantly different from zero.

[23] We use more decimals than shown for the numbers in Table 1, so the reader's calculation may give a slightly different result.

[24] We multiply 6.5 by the coefficient –0.143 in in Table 3, column 1.

6) and decreasing overall emissions (column 3 and 4). Interestingly, the changes in registration taxes over the period 2001-2010 have caused extant diesel drivers to choose more CO_2-intensive cars on average. For these drivers, the effect of lower registration tax levels in 2010 compared to 2001 dominates the effect of the increased CO_2 sensitivity.

Along the same lines, we find that higher petrol fuel taxes tend to increase the diesel share and reduce the fleet's emission intensity (columns 2,4,5,6), while diesel fuel taxes tend to decrease the share of diesel cars, increasing the average emissions (column 2 and 4), though the effect is weak. The finding is consistent with Ryan et al. (2009), but a subtle and important distinction from the general conclusion in the literature that higher *petrol* prices tend to lead to more fuel efficient cars (Davis and Kilian 2011, Burke and Nishitateno 2013, Klein and Linn 2013).

6.3   Transmission mechanisms

Finally, we present a brief assessment of the transmission channels through which fiscal car taxes change emissions. We have already seen that consumers switch between petrol and diesel cars, in response to tax measures, but within a fuel type, they can also respond to tax measures by switching to lighter cars with less powerful engines, or alternatively, they can choose for cars with more fuel efficient engines while keeping the preferred car specifications unaffected (Fontanas and Zamaras, 2010).

In Table 4 we present, for diesel and petrol separately, the effect of fiscal measures on the CO_2 intensity with and without additional controls for average vehicle mass and engine power. If controlling for mass or power reduces the (absolute) value of the policy coefficient, this can be taken as an indication that part of the policy's effect is transmitted through the car features. Next, we estimate the direct effect of fiscal policies on average vehicle mass and engine power. In all models, we control for convergence, income, time and country fixed effects.

To allow easy comparison, columns 1 and 5 in Table 4 reproduce Table 2 columns 1 and 5 respectively. Column 2 and 6 confirm that larger cars with more powerful engines have higher emission intensities. For diesel cars, registration taxes do not significantly affect average mass or engine power of newly purchased vehicles, although adding these features does slightly reduce the (absolute) coefficient on registration taxes in column 2 compared to column 1. A similar effect is found for the CO_2 sensitivity of diesel registration taxes. One possible interpretation of this finding is that higher and more CO_2-sensitive

diesel registration taxes push the technology frontier for cars, providing the same qualities (mass and horsepower) to the consumers, at lower CO_2 emissions. For petrol cars, the effects of registration taxes appear to be transmitted through the car features: higher (CO_2 sensitivity of) registration taxes reduce the average mass and horse power of newly purchased vehicles, even when controlling for the diesel share. There is less indication of a technology effect, and more evidence of switch in the type of cars bought by consumers.

We note that the effects of income on CO_2 intensities appear to be fully transmitted through car features, both for diesel and petrol cars. Such an outcome is intuitive, as increasing income will be used mainly to increase the level of desirable features. The effect of income on CO_2 intensity does not become significantly negative when controlling for mass and horse power, so we find no evidence that consumers use income increases to purchase more environmentally friendly cars. For diesel cars, the effect of diesel fuel taxes is also fully transmitted through the car features.

Table 2. Dependence of new car fleet emissions on taxes, per fuel type

Dependent variable	(log) CO_2 intensity diesel				(log) CO_2 intensity petrol			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TAX registration	−0.165*	−0.021	−0.163*	−0.028	−0.086	−0.030	−0.073	−0.028
CO2TAX registration	−0.045	−0.099***	−0.049*	−0.095***	−0.119**	−0.136***	−0.124**	−0.136***
TAX road	−0.334	0.157			1.855***	1.624***		
CO2TAX road	−0.240	0.369			1.014***	1.018***		
Diesel share	−0.155***		−0.149***		−0.069***		−0.059***	
(log) income	0.128*	0.251***	0.136**	0.233***	0.132***	0.196***	0.098**	0.150***
Fuel tax rate	−0.226***	−0.302***	−0.225***	−0.303***	0.034	−0.048	0.079	0.004
Convergence	−0.030**	−0.051***	−0.032**	−0.048***	−0.020**	−0.029***	−0.022**	−0.030***
Time dummies	Yes	yes	Yes	Yes	Yes	Yes	yes	Yes
Country dummies	Yes	yes	Yes	Yes	Yes	Yes	yes	Yes
Observations	150	150	150	150	150	150	150	150
R-squared	0.929	0.915	0.929	0.914	0.975	0.973	0.973	0.970

Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3. Dependence of car emissions (aggregated over fuels) and diesel share on taxes.

Dependent variable	(log) CO2 intensity overall				Diesel share	
	(1)	(2)	(3)	(4)	(5)	(6)
TAX registration petrol	−0.107	−0.142	−0.079	−0.109	0.187	0.279
CO2TAX registration petrol	−0.055	−0.065	−0.056	−0.047	0.096	−0.030
TAX road petrol	0.436	−1.034			12.45***	
CO2TAX road petrol	0.389	0.335			0.363	
TAX registration diesel	0.071	0.237**	0.033	0.188*	−1.164***	−1.094***
CO2TAX registration diesel	−0.027	−0.063**	−0.020	−0.057**	0.249***	0.258**
TAX road diesel	0.565	2.272***			−14.43***	
CO2TAX road diesel	0.178	0.432			−1.342	
Diesel share	−0.143***		−0.155***			
(log) income	0.066	0.157***	0.045	0.148***	−0.591***	−0.693***
Fuel tax rate diesel	0.005	0.070*	−0.033	0.031	−0.421	−0.251
Fuel tax rate petrol	−0.012	−0.183**	0.072	−0.180**	1.172***	1.156***
Convergence	−0.019**	−0.030***	−0.020**	−0.049***		
Time dummies	yes	Yes	Yes	Yes	yes	Yes
Country dummies	yes	Yes	Yes	Yes	yes	Yes
Observations	150	150	150	150	150	150
R-squared	0.979	0.974	0.978	0.968	0.958	0.923

Significance: *** p<0.01, ** p<0.05, * p<0.1

Table 4. Transmission of fiscal policies to CO_2 intensity

Dependent variable (logs)	diesel				petrol			
	CO2	CO2	mass	horse power	CO2	CO2	mass	horse power
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mass (log)		0.772***				0.516***		
Horse power (log)		0.288***				0.143***		
TAX registration	-0.165*	-0.024	-0.014	-0.185	-0.086	-0.016	-0.097	-0.229
CO2TAX registration	-0.045	-0.038**	0.002	-0.024	-0.119**	-0.000	-0.156***	-0.260***
TAX road	-0.334	-0.102	-1.505**	0.823	1.855***	0.493	1.594***	3.580***
CO2TAX road	-0.240	-0.130	-0.684*	0.546	1.014***	0.193	1.038***	1.896***
Diesel share	-0.155***	-0.037*	-0.086**	-0.104**	-0.069***	-0.042***	-0.042	-0.045
(log) income	0.128*	-0.016	0.114*	0.193**	0.132***	-0.018	0.166***	0.420***
Fuel tax rate	-0.226***	0.031	-0.240***	-0.294**	0.034	0.051	-0.023	0.034
Convergence	-0.030**	-0.048***	-0.003	-0.008	-0.020**	-0.006	-0.014*	-0.010
Time dummies	Yes	Yes	yes	Yes	Yes	Yes	yes	Yes
Country dummies	Yes	Yes	yes	Yes	Yes	Yes	yes	Yes
Observations	150	150	150	150	150	150	150	150
R-squared	0.929	0.976	0.876	0.929	0.975	0.992	0.952	0.965

Significance: *** p<0.01, ** p<0.05, * p<0.1

7   Discussion

We find empirical evidence that fiscal vehicle policies significantly affect emission intensities of new bought cars. Increasing CO_2-sensitivity of registration taxes and higher fuel taxes lead to the purchase of more fuel efficient cars, but higher annual road taxes have no or an adverse effect. The former is consistent with the literature; the latter is counter-intuitive, possibly because annual road taxes are not salient, but the high collinearity between annual road taxes may also play a role. We decomposed the vehicle registration tax rate into two variables, the level and CO_2-sensitivity, and found that especially the CO_2-sensitivity is an important determinant of the emission intensity of new cars. A one percent increase in the CO_2 sensitivity of vehicle purchase taxes reduces the CO_2 intensity of the average new vehicle by 0.04 to 0.13 percent. The changes in registration taxes from 2001 to 2010 have reduced the CO_2 emission intensity of the average new car by 1.3%. The diesel-petrol substitution induced by changes in the relative taxes for diesel versus petrol cars is an important factor for the average fleet's fuel efficiency. We also find higher CO_2 intensities with increasing income and a clear convergence pattern between EU countries.

There is a clear positive potential for fiscal instruments as part of the set of policy measures aimed at reducing CO_2 emissions from cars.[25] Our findings thus support the European Commission's third policy pillar. Yet, we should not overstate the contribution of registration taxes. The overall effect of the registration tax changes that we identify, a 1.3% improvement of fuel efficiency, is small compared to the overall achievement over the period observed (Figure 1). Innovation and other policy instruments have played a substantial role. In that context, it is important to understand that various policy instruments can strengthen, but also counter each other. In the European Directive EC/443/2009 car manufacturers are evaluated (from 2015 onwards) based on their average emissions of cars sold across all EU countries. Increased sales of fuel efficient cars in one country thus allows manufactures to sell more fuel inefficient cars in other countries. The principle, sometimes referred to as a 'waterbed-effect', implies that environmental gains from fiscal national policies can leak away as the sale of more fuel-

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[25] See Burke (2014) for a broader discussion.

efficient cars in a country with a fiscal regime that puts a large premium on CO_2 emissions, is countered by the sale of more fuel-intensive cars in other countries. National fiscal policies, aimed at the demand side, and in line with the third pillar of EU-policies, might thus be less effective conditional on the effectiveness of the first pillar of EU-policy, aimed at the supply of fuel efficient cars throughout the EU.Given an exogenously set ceiling for the EU-wide CO_2 emissions, there is no clear economic gain from a diversified fiscal regime between EU countries, while there are social costs (Hoen and Geilenkirchen, 2006). Indeed, a few years ago, the EU proposed to harmonize vehicle taxes in the EU, but the proposal was rejected by the Member States. We also mention a few other potential disadvantages of fiscal support of fuel efficient cars.

In this paper, we focus on the *average* emission intensity of new cars. Reducing taxes for small, fuel-efficient cars can lead to scale effects (i.e. more cars) and intensity-of-use effects (i.e. more kilometres per car). Konishi and Zhao (2014) show that in a green tax reform in Japan, this scale effect offset the composition effect (i.e. a bigger share of fuel-efficient cars) by approximately two third. In addition, there is a rebound effect. Fuel-efficient cars are cheaper to drive, and a portion of the CO_2 gains by CO_2-based vehicle purchase tax is lost as the fuel-efficient cars increase car travel demand (Khazoom, 1980). The existence of the effect is undisputed, but its magnitude remains an issue of debate (see e.g. Brookes, 2000, Binswanger, 2001, Sorrell and Dimitropoulos, 2008). Frondel and Vance (2014) estimated that 44-71% of potential energy savings from efficiency improvements in Germany between 1997 and 2012 were lost due to increased driving. The rebound effect may be mitigated if part of the increase in sales of new, clean cars is due to consumers sooner retiring their less-efficient cars.

Of the policies aimed at reducing CO_2 emissions, excise fuel duties most directly target the environmental objective, specifically since the use of the car is accountable for about 80% of CO_2 emissions in its life-cycle (E. Gbeghaje-Das 2013). Fuel excise duties are also closer to the 'polluter pays-principle', one of the leading principles of European Environmental Policy (European Parliament and Council, 2004). Taxing fuels would lead to more efficient cars and lower mileage without rebound effects (Cropper and Chugh, 2014), making it the preferred instrument for reducing road transport emissions. Yet significant fuel tax increases are politically costly.

There are also secondary effects of fiscal policies. When consumers choose lighter cars that are more fuel efficient, not only CO_2 emissions fall but emissions of NO_x and PM_{10}

as well. A weight reduction of 10% results in a decrease of the emission of NO_x with 3-4% (Nijland et al., 2012). On the other hand, substituting diesel cars for petrol cars improves CO_2 fuel efficiency by about 10-20%, yet increases the emissions of NO_x (Nijland et al., 2012). In the case of PM_{10} the situation is not clear, as modern petrol cars with direct injection might emit more PM_{10} than modern diesel cars (Köhler, 2013). Lighter cars also reduce fatalities for drivers of other vehicles, pedestrians, bicyclists, and motorcyclists (Gayer 2004, White 2004). The design of the fiscal regime, encouraging lighter cars or encouraging diesel cars, can alter the secondary effects substantially.

We used CO_2 emission data according to the NEDC guidelines. It is known that the tests typically report lower emissions compared to realistic conditions, especially for cars that score very well at the tests (Ligterink and Bos, 2010, Ligterink and Eijk, 2014). Moreover, the gap between test results and realistic estimates for normal use have increased over time; from about 8% in 2001 to 21% in 2011, with a particularly strong increase since 2007 (Mock et al. 2012, ICCT, 2014). The gap between test values and estimates of realistic use values also affects the estimated emission of air pollutants, particularly the emissions of NOx from diesel cars (e.g. Hausberger, 2006, Vonk and Verbeek, 2010). To continue the use of test-cycles therefore requires an update of procedures and improvement of their reliability as predictor of real-life use.

Finally, we mention three limitations of our study. We proxy the fiscal treatment of personal vehicles, assuming that taxes change continuously with CO_2 emissions. Yet, there are indications that consumers are more sensitive to discrete price increases, such as tax breaks for cars that meet specific criteria (see e.g. Finkelstein, 2009, Klier and Linn, 2012, Kok, 2013). This study did not explicitly model these elements of tax design. Second, about half of the new sales in Europe are company cars (Copenhagen Economics, 2010). One of the reasons for their widespread use is their beneficial tax treatment (Gutierrez-i-Puigarnau and van Ommeren, 2011), including implicit subsidies as employees often do not bear the variable costs of private use (Copenhagen Economics, 2010). Therefore, private consumers and business consumers react differently to price signals such as fiscal rules and fuel taxes. We do not have available data on the two separate markets and must leave this topic to future research. Third, we did not consider other fiscal measures such as the scrap subsidies which had major effects on sales in various countries, though the effects on the fuel efficiency is considered limited (Leheyda and Verboven, 2013).

8 References

ACEA European Automobile Manufacturers Association (2010), ACEA Tax Guide, 2001-2010 edition, Brussels

Achtnicht M (2012), German car buyers' willingness to pay to reduce CO2 emissions, *Climatic Change* 113:679-697.

Anderson, S. P., A. de Palma and B. Kreider (2001), Tax incidence in differentiated product oligopoly, *Journal of Public Economics* 81(2): 173-192.

Berry, S., J. Levinsohn and A. Pakes (1995), Automobile Prices in Equilibrium, *Econometrica*, 63(4):841-890.

Blanco G., R. Gerlagh, S. Suh, et al., 2014: Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Binswanger, M. (2001), Technological Progress and Sustainable Development: What about the Rebound Effect? *Ecological Economics*, 36, 119-132.

Brand, C., J. Anable & M. Tran (2013), 'Accelerating the transformation to a low carbon passenger transport system. The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK', *Transportation Research Part A: Policy and Practice* (49): 132-148.

Brookes, L. (2000), Energy Efficiency Fallacies Revisited, *Energy Policy,* 28, 355-367.

Burke PJ and S Nishitateno (2013), Gasoline prices, gasoline consumption, and new-vehicle fuel economy: Evidence for a large sample of countries. *Energy Economics* 36: 363-370.

Burke PJ (2014), Green Pricing in the Asia Pacific: An Idea Whose Time Has Come?, Asia & the Pacific Policy Studies 1: 561–575.

Campestrini M. and Mock P. (2011), European Vehicle market Statistics, ICCT, Washington

Ciccone A. (2014), Is it all about CO2 emissions? The effects of green taxation for new vehicles in Norway, Memorandum, Department of Economics, University of Oslo 19/2014

Copenhagen Economics (2010), Company car taxation, Working Paper 22, Copenhagen.

Cropper M., Chugh R. (2014), The Welfare Effects of Fuel Conservation Policies in the Indian Car market, WCERE conference, Istanbul

Davis LW and L Kilian (2011), Estimating the Effect of a Gasoline Tax on Carbon Emissions, *Journal of Applied Econometrics*, 16 : 1187-1214.

DellaVigna, S. (2009), 'Psychology and Economics. Evidence from the Field', *Journal of Economic Literature* 47(2): 315-372.

D'Haultfoeuille, X., P. Givordz, X. Boutinx (2014) The Environmental Effect of Green Taxation: The Case of the French "Bonus/Malus.", *The Economic Journal,* Vol. 124, Issue 578, 444-480,

EEA European Environment Agency (2013), Monitoring CO2 emissions from new passenger cars in the EU: summary of data for 2012, Copenhagen. Data files available at www.eea.europa.eu/data-and-maps/data/ds_resolveuid/61bf022022044c748fecc33143dbcbbd.

European Commission (1995), A Community strategy to reduce CO2 emissions from passenger cars and improve fuel economy. Communication from the Commission to the Council and the European Parliament. COM (95) 689 final, 20 December 1995, Brussels.

European Commission (2005), Proposal for a council directive on passenger car related taxes, COM(2005) 261 final, Brussels.

European Commission (2011a), Price car reports, http://ec.europa.eu/competition/sectors/motor_vehicles/prices/archive.html.

European Commission (2011b), Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system , COM(2011) 144 final, Brussels.

European Commission (2014), Excise Duty Tables, https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp.

European Parliament and Council (2004), Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage, Brussels.

European Parliament and Council (2009), Regulation No 443/2009 of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles, Brussels.

Eurostat (2014) GDP and main components - volumes (nama_gdp_k), available at epp.eurostat.ec.europa.eu/portal/page/portal/national_accounts/data/database

Finkelstein, A. (2009). E-Ztax: Tax Salience and Tax Rates. *Quarterly Journal of Economics* 124(3): 969–1010.

Fontaras G and Z Samars (2010), On the way to 130gCO2/km — Estimating the future characteristics of the average European passenger car. *Energy Policy* 38: 1826-1833.

Frondel M., Vance C. (2014), Fuel Taxes versus Efficiency Standards: An Instrumental Variable Approach, WCERE conference, Istanbul

Gallagher, K.S. & E.J. Muehlegger (2011), 'Giving green to get green. Incentives and consumer adoption of hybrid vehicle technology', *Journal of Environmental Economics and Management* (61): 1–15.

Gayer T (2004), The Fatality Risks of Sport-Utility Vehicles, Vans, and Pickups Relative to Cars, J. of Risk and Uncertainty 28:103-133.

Gbeghaje-Das, E., (2013), Life Cycle CO2 assessment of low carbon cars, PE consultants, London.

Greene, D., P. Patterson, M. Sing & J. Li (2005), 'Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy', *Energy Policy* (33): 757-775.

Greene, D., D.H. Evans & J. Hiestand (2013), 'Survey evidence on the willingness of U.S. consumers to pay for automotive fuel economy'*, Energy Policy* (61): 1539-1550.

Gutierrez-i-Puigarnau, E. and van Ommeren, J.N.(2011), Welfare effects of distortionary fringe benefits taxation: the case of employer-provided cars, *International Economic Review,* 52(4), 1105-1122.

Hausberger S., (2006), Fuel Consumption and Emissions of Modern Passenger Cars, Institute for Internal Combustion Engines and Thermodynamics, Report Nr. I-25/10 Haus-Em 07/10/676, Graz.

Hennessy, H. & R.S. Tol (2011), 'The impact of tax reform on new car purchases in Ireland', *Energy Policy* (39): 7059–7067.

Hoen, A. & G.P. Geilenkirchen (2006), De waarde van een SUV - waarom de gemiddelde auto in Nederland niet zuiniger wordt. Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk 2006, 23 en 24 november 2006, Amsterdam.

Huse C. and C. Lucinda (2013), The Market Impact and the Cost of Environmental Policy: Evidence from the Swedish Green Car Rebate*, Economic Journal* 124:393-419.

ICCT (2014), From laboratory to road. A 2014 update of official and "real-world" fuel consumption and CO2 values for passenger cars in Europe, International Council on Clean Transportation Europe, Berlin.

Khazoom, D.J. (1980), Economic Implications of Mandated Efficiency Standards for Household appliances, *The Energy Journal* 1, 21-40.

Kilian, L., Sims E. (2006), The Effects of Real Gasoline Prices on Automobile Demand: A Structural Analysis Using Micro Data,Working Paper, University of Michigan, Ann Arbor.

Klier, T., Linn J. (2012), Using Vehicle Taxes to Reduce Carbon Dioxide Emissions Rates of New Passanger Vehicles: Evidence from France, Germany, and Sweden, MIT CEEPR Working Paper 2012-011, Cambridge, USA.

Klier T and J Linn (2013), Fuel prices and new vehicle fuel economy — Comparing the United States and Western Europe, JEEM 66: 280-300.

Köhler, F. (2013), Testing of particulate emissions from positive ignition vehicles with direct fuel injection system, Technical Report, 2013-09-26, TűV Nord

Kok, R (2013). New car preferences move away from greater size, weight and power: Impact of Dutch consumer choices on average CO2-emissions., *Transportation Research. Part D: Transport & Environment*, 21 (June), 53-61.

Konishi Y., and M. Zhao (2014), Can Green Car Taxes Restore Efficiency? Evidence from the Japanese New Car Market, Tokyo Center for Economic Research Working Paper E-82

Leheyda N. and F. Verboven (2013), Scrapping Subsidies during the Financial Crisis - Evidence from the Europe, mimeo, University of Leuven

Leinert, S., Daly, H., Hyde, B. & Gallachóir, B. Ó. (2013), Co-benefits? Not always: Quantifying the negative effect of a CO2-reducing car taxation policy on NOx emissions, *Energy Policy*, (63): 1151–1159.

Ligterink, N.E., Bos B. (2010), CO2 uitstoot van personenwagens in norm en praktijk – analyse van gegevens van zakelijke rijders, TNO report MON-RPT- 2010-0014, Delft.

Mabit, S.L. (2014), Vehicle type choice under the influence of a tax reform and rising fuel prices, *Transportation Research Part A*, 64 (2014) 32–42.

Mannering, F., Winston, C. (1985), A dynamic empirical analysis of household vehicle ownership and utilization, *RAND Journal of Economics* 16 (2), 215-236.

Mock P., German J., Bandivadekar A., Riemersma I. (2012), Discrepancies between type-approval and "real-world" fuel-consumption and CO2 values, Assessment for 2001-2011 European passenger cars, ICCT working paper 2012-2

Meerkerk, J. van, G. Renes & G. Ridder (2014), Greening the Dutch car fleet: the role of differentiated sales taxes, PBL Working Paper 18, Den Haag: PBL.

Nijland H., Mayeres I., Manders T., Michiels H., Koetse M., Gerlagh R. (2012), Use and effectiveness of economic instruments in the decarbonisation of passenger cars, ETC-ACM Technical Paper 2012/11, Bilthoven.

Rogan, F., E. Dennehy, H. Daly, M. Howley & B.P.Ó. Gallachóir (2011), 'Impacts of an emission based private car taxation policy. First year ex-post analysis', *Transportation Research Part A:Policy and Practice* (45), 583- 597.

Ryan L., S. Ferreira, and F Convery, (2009), The impact of fiscal and other measures on new passenger car sales and CO2 emissions intensity: Evidence from Europe, *Energy Economics* 31: 365-374.

Sims R., R. Schaeffer, et al., 2014: Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sorrell, S., Dimitroupolos, J. (2008), The rebound Effect: Microeconomic Definitions, Limitations and Extensions, *Ecological Economics,* 65 (3), 636-649.

Vonk W.A., Verbeek R. P. (2010), Verkennende metingen van schadelijke uitlaatgasemissies van personenvoertuigen met euro6-dieseltechnologie, TNO-rapport MON-RPT-2010-02278, Delft.

White MJ (2004), The "arms race" on American roads: the effect of sport utility vehicles and pickup trucks on traffic safety, *J. of Law and Economics* 47: 333-355.

9   Appendix

9.1   Loglinear detailed model of Section 3.2

We construct the country-car-year variables $LOGCO2_{it}=\ln(CO2_{it})$ and $LOGTAX_{cit}=\ln(1+\tau_{cit})$ from our database, and subsequently construct the country averages (equations (8) and (9)), denoted by a bar over the variables:

$$\overline{LOGCO2}_{ct} = \frac{\sum_i \delta_{cit} LOGCO2_{it}}{\sum_i \delta_{cit}} \qquad (17)$$

$$\overline{LOGTAX}_{ct} = \frac{\sum_i \delta_{cit} LOGTAX_{cit}}{\sum_i \delta_{cit}} \qquad (18)$$

We subsequently calculate the CO2-sensitivity of the tax (10), *LOGCO2TAX$_{ct}$*, by comparing how much taxes increase when CO2 emissions increase, on average, and weighted:

$$LOGCO2TAX_{ct} = \frac{\sum_i w_{cit}(LOGTAX_{cit} - \overline{LOGTAX}_{ct})}{\sum_i w_{cit}(LOGCO2_{cit} - \overline{LOGCO2}_{ct})} \tag{19}$$

where weights are given by the deviation from the average CO2 intensity (11):

$$w_{cit} = (LOGCO2_{cit} - \overline{LOGCO2}_{ct}) \tag{20}$$

We then construct the (virtual) tax rate *LOGTAX$_{ct}$* that would apply to a car with a CO2-emission profile that is typical for the aggregate of all countries (12) (13):

$$L\widetilde{OGCO}2_t = \frac{\sum_{c,i} \delta_{cit} LOGCO2_{cit}}{\sum_{c,i} \delta_{cit}} \tag{21}$$

$$LOGTAX_{ct} = \overline{LOGTAX}_{ct} + LOGCO2TAX_{ct}(L\widetilde{OGCO}2_t - \overline{LOGCO2}_{ct}) \tag{22}$$

The two constructed variables *LOGTAX$_{ct}$* and *LOGCO2TAX$_{ct}$*, are used as independent variables explaining the average emission intensity of the new car fleet (14). Note that the country-average CO2 intensity constructed in (8) or (17) is *not* the same variable used in the econometric regression, used as independent variable in Section 4 (14). The country-average CO2 intensity in (8) or (17) is measured only for those car types for which we have price and tax data, and its purpose is solely to construct the CO2 sensitivity of car taxes in (10) or (19). The country-average CO2 intensity used in Section 4 (14) is from an independent source, and is based on all car sales in a country-year; it is the independent variable that we explain using the country tax variables constructed in Section 3.2.

9.2 Linear model

In the main text, we characterized a country's tax system by two coefficients: the average rate, and its CO2 sensitivity, which is defined as *elasticity* of the tax *rate* with respect to CO2 emissions. In this appendix, we take a linear approach. Here, the CO2 sensitivity is instead defined as the increase in the tax *level* for a given increase in CO2 emissions (in grams per km). To decompose the tax in these elements, we estimate

$$\tau_{cit} = TAX_{ct}p_{cit}^p + CO2TAX_{ct}(CO2_{cit} - \overline{CO2}_t)$$

where τ_{cit} is the tax paid (in euro's) for vehicle i in country c at time t, p_{cit}^p is the tax exclusive purchase price, $CO2_{cit}$ the vehicle CO2 emission in g/km and $\overline{CO2}_t$ the average time t CO2 emissions in g/km. We then characterize a tax system by TAX_{ct}, which is the average tax *rate* as a percentage of the purchase price, and $CO2TAX_{ct}$ which is the additional tax, in euro's, per g/km additional CO2 emissions.[26]

Table 4 presents the summary statistics equivalent to Table 1, as the numbers in this table are potentially easier to interpret. Consistent with the results for the logarithmic model, we find that from 2001 to 2010, the average registration taxes have fallen, yet its CO2 sensitivity has increased, for petrol and diesel cars. For example, for diesel cars, the average registration tax fell from 53 percent in 2001 to 44 percent in 2010. In 2001 however, emitting an additional 10 gCO_2/km would increase the tax by 88 euros on average. In 2010, this has increased to 382 euros. Adjusting the decomposition slightly alters the estimation of the average tax rate. In Table 1, the 2001 (2010) diesel registration tax rate is 46 (40) percent, for petrol this is 39 (34) percent; in Table 4 these rates are approximately 7 percentage points higher.

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[26] Note that this simultaneous estimation of TAX_{ct} and $CO2TAX_{ct}$ is not a departure from the decomposition strategy in Section 4.2, as the decomposition in the main text is equivalent to estimating $\tau_{cit} = TAX_{ct} + CO2TAX_{ct}(CO2_{cit} - \overline{CO2}_t)$, with all variables as defined in Section 4.2.

Table 5: Summary statistics for constructed coefficients for EU15 – linear model[*]

		2001-2010				2001	2010
		Mean	Std. Dev	Min	Max	Mean	Mean
Vehicle registration tax rate	Diesel	0.50	0.53	0.16	2.23	0.53	0.44
	Petrol	0.47	0.46	0.15	1.93	0.46	0.42
Vehicle registration tax, CO2 sensitivity	Diesel	17.4	33.74	-22.31	92.88	8.8	38.2
	Petrol	23.2	34.62	-2.73	127.72	20.5	32.3
Road tax rate	Diesel	0.02	0.01	0	0.05	0.02	0.02
	Petrol	0.01	0.02	0	0.07	0.02	0.01
Road tax, CO2 sensitivity	Diesel	–0.48	2.43	-8.88	1.10	–1.38	0.28
	Petrol	–0.83	3.04	-10.71	1.04	–1.48	–0.02

[*]Tax rates are measured as percentage of the tax exclusive purchase price, CO2 sensitivity in euro per gCO2/km.

Note: For this table, data are not weighted.

With this decomposition, we consider the effect of the vehicle registration tax rate, and the CO_2 sensitivity of the tax paid on the average CO_2 intensity of newly purchased vehicles. Results are presented in Tables 6 and 7. Since we now take the level of the additional tax on CO_2 emissions, and the level of the average CO_2 intensity of newly purchased vehicles interpretation is slightly different compared to Tables 2 and 3. Take for example the first column of Table 6. Here, a 10 percentage point increase in the vehicle registration tax rate is expected to reduce the CO_2 intensity of diesel cars by 2.2 gCO_2/km. Similarly, the (insignificant) coefficient of -0.005 on CO2TAX registration implies that a 10 euro increase in the effective registration tax rate on CO_2 emissions for diesel cars, is expected to reduce the average CO_2 intensity of diesel cars by 0.05 gCO_2/km. In terms of sign and significance, results are in line with the logarithmic model in the main text.

Table 6. Dependence of new car fleet emissions on taxes, per fuel type, linear model

Dependent variable	CO2 intensity diesel				CO2 intensity petrol			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TAX registration	-22.51***	-7.973	-20.42***	-6.329	0.287	2.892	0.395	2.620
CO2TAX registration	-0.005	-0.032*	-0.0004	-0.033*	-0.053**	-0.072***	-0.067***	-0.079***
TAX road	74.23	101.1			194.8**	120.3		
CO2TAX road	-0.254	-0.087			0.638*	0.526		
Diesel share	-30.04***		-29.04***		-9.748**		-7.828**	
(log) income	11.76	36.76***	16.68*	38.64***	21.69***	29.59***	19.16***	25.92***
Fuel tax rate	-18.70*	-35.50***	-20.92**	-36.71***	1.168	-5.332	3.633	-2.812
Convergence	-0.014	-0.043**	-0.020	-0.045***	-0.040***	-0.047***	-0.044***	-0.049***
Time dummies	Yes	Yes	Yes	Yes	yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	yes	Yes	Yes	Yes
Observations	150	150	150	150	150	150	150	150
R-squared	0.932	0.909	0.930	0.908	0.975	0.974	0.974	0.973

Significance: *** p<0.01, ** p<0.05, * p<0.1

Table 7. Dependence of car emissions (aggregated over fuels) and diesel share on taxes, linear model.

Dependent variable	CO2 intensity overall				Diesel share	
	(1)	(2)	(3)	(4)	(5)	(6)
TAX registration petrol	-6.381	-5.691	-5.500	-5.859	-0.134	-0.035
CO2TAX registration petrol	-0.010	-0.030	-0.013	-0.027	0.001	0.0006
TAX road petrol	-47.73	-286.5***			11.78***	
CO2TAX road petrol	0.525	0.630			-0.019*	
TAX registration diesel	6.649	12.27*	6.116	13.04*	-0.243	-0.310
CO2TAX registration diesel	-0.016	-0.027*	-0.010	-0.022	0.0005	0.0006
TAX road diesel	267.4***	457.3***			-12.09***	
CO2TAX road diesel	0.128	0.080			0.019**	
Diesel share	-20.73***		-23.93***			
(log) income	12.74**	25.18***	10.04*	27.51***	-0.623***	-0.799***
Fuel tax rate diesel	-6.036	-3.061	-9.646	-4.152	-0.062	-0.016
Fuel tax rate petrol	3.758	-10.88	7.313	-18.06**	0.532***	0.725***
Convergence	-0.029***	-0.042***	-0.039***	-0.064***		
Time dummies	yes	Yes	Yes	yes	Yes	yes
Country dummies	yes	Yes	Yes	yes	Yes	yes
Observations	150	150	150	150	150	150
R-squared	0.981	0.976	0.979	0.970	0.952	0.921

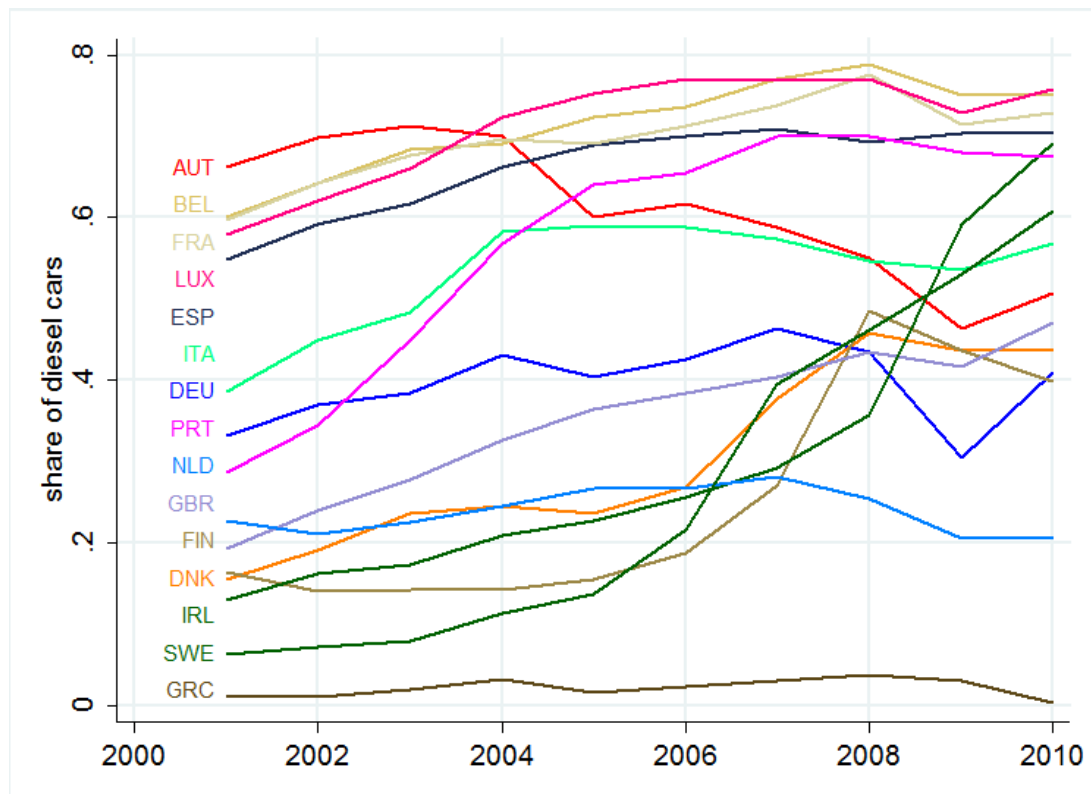Significance: *** p<0.01, ** p<0.05, * p<0.1

9.3 Additional figures

Figure 6: Share of diesel cars in new fleet.

Table 7: Correlation between fiscal vehicle measures

| | | | Registration | | | | Annual | | | | Fuel | |
| | | | Petrol | | Diesel | | Petrol | | Diesel | | Petrol | Diesel |
			level	CO2	level	CO2	level	CO2	level	CO2		
Registration	Petrol	level	1.00									
		CO2	-0.38	1.00								
	Diesel	level	**0.67**	-0.16	1.00							
		CO2	-0.21	**0.61**	0.24	1.00						
Annual	Petrol	level	0.07	-0.09	0.13	-0.07	1.00					
		CO2	-0.05	0.10	-0.13	0.12	**-0.89**	1.00				
	Diesel	level	0.00	-0.09	0.08	-0.10	**0.85**	**-0.75**	1.00			
		CO2	0.08	0.13	0.02	0.18	**-0.75**	**0.84**	**-0.75**	1.00		
Fuel	Petrol		-0.03	0.09	-0.04	0.01	0.04	-0.07	0.04	-0.13	1.00	
	Diesel		-0.03	0.10	0.03	0.07	0.14	-0.06	0.15	-0.10	**0.75**	1.00

Correlations for variables after taking out time and country fixed effects. In bold those >0.5. Annual taxes are multi-collinear.