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Greening the Vehicle Fleet: Evidence from Norway's CO_2 Differentiated Registration Tax

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Greening the Vehicle Fleet: Evidence from Norway's CO_2 Differentiated Registration Tax

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Abstract

Fiscal policies are used to improve vehicle fuel efficiency and reduce CO_2 emissions in the transport sector. Years of forceful reform in Norway may be seen as informative. From 2007, Norway has linked its new vehicle registration tax to CO_2 intensities, later adapting it into a feebate form. We exploit a detailed dataset of new vehicle registrations, using fixed effects and instrumental variables in our econometric analysis. We find that the CO_2 differentiated registration tax contributes significantly to shifting purchases towards low-emitting cars. A 1000NOK tax increase (about 120USD) is associated with a reduction of 1.13% - 1.58% in vehicle registrations, and the responsiveness in car choice to fuel costs is of the same magnitude. The estimated effect of the tax explains the majority (79%) of the reduction in average CO_2 intensity in the new car fleet 2006 through 2011. A point estimate of the elasticity of the CO_2 intensity with respect to the CO_2 price is minus 0.06, whereas the elasticity with respect to (resulting) car prices is about minus 0.5. An intuitive model with 'all' car types losing demand to low-emitting types applies fairly well: low-emitting segments gain in share and do not get CO_2 leaner, while high-emitting segments lose in share and become CO_2 leaner. Moves between nine segments and within those segments are equally important.

Keywords: CO_2 intensity, new vehicle, vehicle registration tax, fuel cost, Pigovian taxation, green tax reform, greenhouse gas emission reductions.

1. Introduction

In transport, policy objectives of energy security and GHG emission abatement should be studied together, due to their close relations. For both objectives, studies on vehicle ownership and usership are important. Our research is motivated by the fact that new sales is a major determinant of the future vehicle stock. We study the composition of new vehicles sold – especially CO_2 intensity[1] and fuel efficiency – and how it responds to changes in taxation and fuel prices.

Policy background

Varying by region and country, standards for fuel economy or GHG emissions have been established for passenger vehicles and light-commercial vehicles/light trucks (Atabani, et al., 2011). The European Union first introduced mandatory CO_2 standards for new passenger cars in 2009, and by 2013 reached agreement regarding an emission target of 95 CO_2 g/km averaged over manufacturers combined (Mock, 2014). To influence vehicle demand, fiscal policy instruments, such as fuel taxes and vehicle taxes based on CO_2 intensity are also used. From 2005 to 2010, the number of countries which adopted fiscal policy to reduce light duty vehicle CO_2 emissions (or fuel consumption) increased from 9 to 17 (He and Bandivadekar, 2011).

Norway has had a CO_2 element in its fuel taxes since 1991, and the CO_2 element in its vehicle registration tax has been introduced since January 2007 with the explicit objective to reduce CO_2 emissions from transport sector. The Norwegian vehicle registration tax up to 2006 consisted of three taxes based on elements: weight, engine power and engine size[2]. In 2007, the engine size element was replaced by an element taxing its CO_2 intensities, as reported in the registration document[3]. After 2007, the CO_2 tax has been rising per gram while other parts of the registration have declined. Since 2009, the vehicle registration tax has been adapted into a feebate form by

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[1] CO_2 intensity – in grams per vehicle kilometer – is basically the same as fuel efficiency, once fuel type is given (Smokers et al., 2009). We will speak about "fuel efficiency" and "CO_2 emission rate" and "CO_2 intensity" as equivalent. Fuel-efficient vehicles also means 'low emitting vehicles'. We do not include other pollutants, nor other greenhouse gases, than CO_2. Greenhouse gases other than CO_2 are not important in our study.

[2] Weight/engine power/engine size/CO_2 differentiated tax is a progressive tax based on those vehicle characteristics. The full structure of vehicle registration tax is provided in Appendix TableA2.

[3] The official vehicle CO_2 intensity values are determined by laboratory tests. There is a gap between the real-world and official CO_2 values that has been increasing over time (Tietge, et.al, 2015). Our present study is merely taking these CO_2 intensity values as given, although we should notice that these questions raise the importance of complementary taxation of fuels.

giving rebates to relatively low-emitting vehicles. In recent years, increases in the CO_2 based element account for the main changes. This unorthodox and pioneering tax experiment, together with a very detailed database on new vehicle sales, motivates this study.

Although there has been much research on fuel economy, only a few papers have contributed empirical ex-post analysis of CO_2 differentiated vehicle taxation. Examples of discrete choice models/multinomial logit models are: Germany (Adamou et al., 2012a), Ireland (Giblin and McNabola, 2009), France (D'Haultfoeuille et al., 2013), Sweden (Huse and Lucinda, 2014)) and Greece (Adamou et al., 2012b). Another econometric technique is single-equation methods (Ryan et al., 2009; Michielsen et al., 2015; Klier and Linn, 2015; Rivers and Schaufele, 2016). Ryan et al. (2009) and Michielsen et al. (2015) estimate the impact of CO_2 differentiated vehicle tax on average CO_2 intensities across countries in EU. Klier and Linn (2015) and Rivers and Schaufele (2016) mainly focus on the tax effect on registrations of vehicles with different emission rates in France and Canada. Differently, ex-ante assessment of the potential design and benefits of CO_2 based feebate program is made in a comprehensive study for California by Bunch, et al. (2011).

In this paper, we are interested in the equilibrium relationship between new vehicle registrations and the new vehicle registration tax. To identify the tax effect on vehicle registrations, a vehicle fixed effect and a model-year-quarter fixed effect are used to control for the fixed vehicle characteristics and exogenous shocks to demand-side and supply-side factors that affect new vehicle registrations, such as the progression of European fuel economy standards and technical improvements. Next, we investigate tax effects in different vehicle groups, and relationships between vehicle registrations and vehicle prices, using the tax as an instrumental variable. Last, we use the tax estimate to investigate how the average CO_2 intensity of new vehicles responds to the CO_2 differentiated vehicle tax.

This paper contributes to the literature in three ways. Firstly, we provide insight into the structure of the CO_2 based vehicle tax to address questions of interests to policy decision making. The previous empirical research on this tax in Norway was conducted with a difference in difference approach (Ciccone, 2014). Ciccone (2014) identifies the changes in the CO_2 intensity and the share of diesels cars and share of high-emission cars by treating the introduction of the tax in 2007 as a one-time uniform incident for all vehicles. In contrast, we study the tax structure by presenting the tax reforms that renders different tax liabilities to vehicles with different characteristics[4]. We make use of the quasi-experimental nature of an actual long-running tax on the sale of new vehicles from 2006 to 2011: (i) the tax is based on CO_2 intensity and other vehicle characteristics that differ between and within car models, (ii) time variation is created by reforms, such as the introduction of the tax on CO_2, and also by temporary stimulus, such as changing the tax rates or redefining tax pivot points, and (iii) notches are created by discontinuous jumps in tax rates at threshold values of vehicle characteristics. This enables detailed evaluations and identifies a reduced form purchase response without many of the problems (such as unobserved heterogeneity issues) that can influence a more structural vehicle choice model. Secondly, for robustness analysis, we analyze alternative models in order to be well informed of the limitations and interpretations of our estimation technique and results. We also use an instrumental variables approach to introduce vehicle price information in the evaluation of tax effects. Thirdly, for a better interpretation of the results, we explain economic concepts for the empirical estimations and make counterfactual analyses for policy purposes.

Our main findings are based on data for private passenger vehicle registrations from 2006 to 2011. We observe a consistent reduction in the sales-weighted average CO_2 intensity of new vehicles, from around 177 g/km in 2006 to 134 g/km in 2011. We identify the part of this reduction that is associated with the changes in the new vehicle taxes, while we admit that emission intensities are affected by other factors (e.g. changes in income, technological change, EU policies) which contribute to a net reduction of average CO_2 intensity of the total new vehicle fleet.

Our econometric results show that 1000NOK tax increase is associated with a vehicle type's sales reduction of 1.13% to 1.58% on average. This result is significant and robust. We find that the introduction of this CO_2 differentiated tax in 2007 explains the majority (79%) of the CO_2 emission reductions from 2006 to 2007. We calculate that a one percent increase in the average CO_2 price is associated with 0.06% reduction of average CO_2 intensity, so the elasticity of emissions to the CO_2 price is minus 0.06, or minus six percent. This may sound like a very tiny responsiveness, but appears differently if we realize that the effect goes through car prices, and the CO_2 tax is a moderate contributor to average car costs. The elasticity of the CO_2 intensity to car prices (when the tax changes car prices) is minus fifty percent. An important expected feature demonstrated in

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[4] Tax liability is calculated as sum of tax rates times the CO_2 emission rates/weight/engine power/engine size.

the analysis is that the sales of big and heavy cars is more elastic to the CO_2 price than that of small and light cars. The sales of small and light cars increase when the CO_2 price increases, due to the substitutions from larger and heavier vehicle types.

This paper is organized as follows. Section 2 introduces the vehicle tax and market in Norway. Section 3 presents some economic concepts. In the section 4, empirical approaches are proposed to estimate the tax effect. In the section 5, we present the results from estimation models as well as robustness analysis. In the section 6, counterfactual analysis is made for policy implications. Section 7 is conclusions.

2. The new vehicle registration tax and market in Norway

Our vehicle registration data and the tax reforms extend from 2006 through 2014. But we research on data from 2006 through 2011. The most important reason is that the introduction of a NO_x fee in 2012 lead to our data problems since we do not have NO_x intensity for each vehicle to calculate the tax liability. The research mainly focuses on the purchase/registration of gasoline and diesel cars, since other types of vehicle take up rather small share of the new vehicle sales.

2.1 The CO_2 differentiated vehicle registration tax

Starting from 2007, the Norwegian government undertook consecutive reforms of its vehicle registration tax on new vehicles by introducing a CO_2 based tax on CO_2 intensity of vehicles. Fig. 1 presents the CO_2 tax schedule by year, visualizing the annual adjustments. As a progressive tax based on CO_2 intensity, the tax features discrete jumps in tax rate at cutoffs (or pivot points), represented by the kinks on each line in the Fig. 1. The second main reform took place in 2009, when a subsidy (“rebate”) is introduced to yield a feebate form. The subsidy is shown by the part of lines below the X-axis. Apart from these two main reforms, the vehicle registration tax has been subject to a great deal of policy adjustments over the years, every time by January 1st. The reforms have changed tax rates and pivot points. As a result, they change the tax on vehicles with different CO_2 intensity and other vehicle characteristics. As shown in Fig. 1, from 2006 to 2011, the slopes get steeper since the tax gap between low-emitting and high-emitting vehicles is extended.

As compared to other European countries, Netherland’s scheme is also based on vehicle characteristics, but includes vehicle prices (Kok, 2011). The registration tax can also be fixed taxes or subsidies for emission groups without being continuous in CO_2 intensity, for example French feebate (D'Haultfoeuille, et Al.,2014). Some other countries (e.g. Sweden and Germany), have implemented CO_2 differentiated annual circulation tax. Since the Norwegian CO_2 based vehicle registration tax is smooth and continous, it sends tax/price signal for all steps in CO_2 intensity.

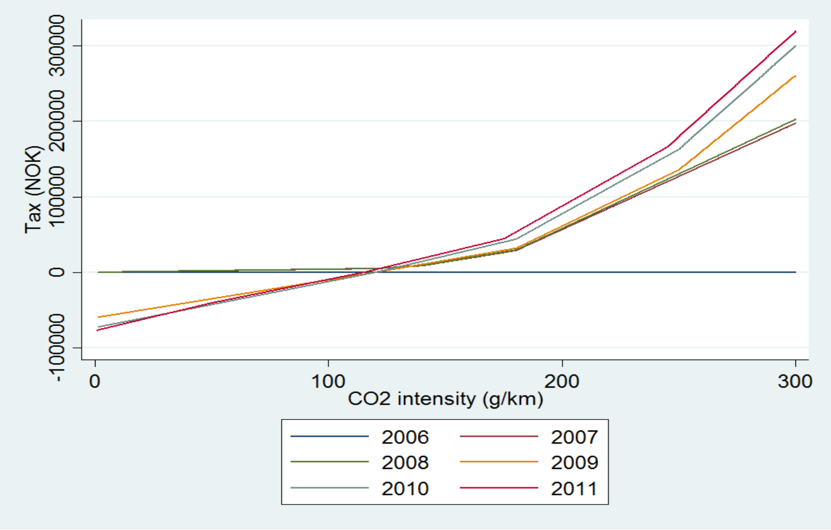

Fig. 1. CO_2 differentiated registration tax in Norway

2.2 New vehicle market

Fig. 2 presents new vehicle registrations monthly from 2006 to 2011, with about 100,000 vehicles annually. The annual vehicle purchase keeps steady except during the financial crisis in 2008 and 2009. There is no obvious seasonal pattern shown in the figure.

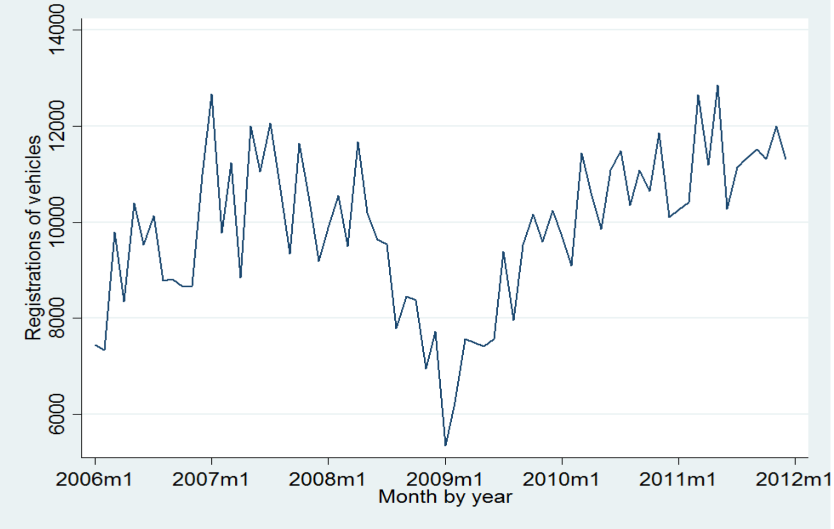

Fig. 2. Monthly new passenger vehicle registrations in Norway, 2006-2011

Fig. 3 shows a downward trend in the sales-weighted average CO_2 intensity for new passenger vehicles from 2006 to 2011. In November and December of 2006, average CO_2 intensity went up dramatically. This reflects that the announcement of new CO_2 differentiated tax came before its implementation[5]. Consumers bought high-emitting vehicles to escape the tax and price increases. Similar but smaller peaks show up right before January every year before annual tax adjustments.

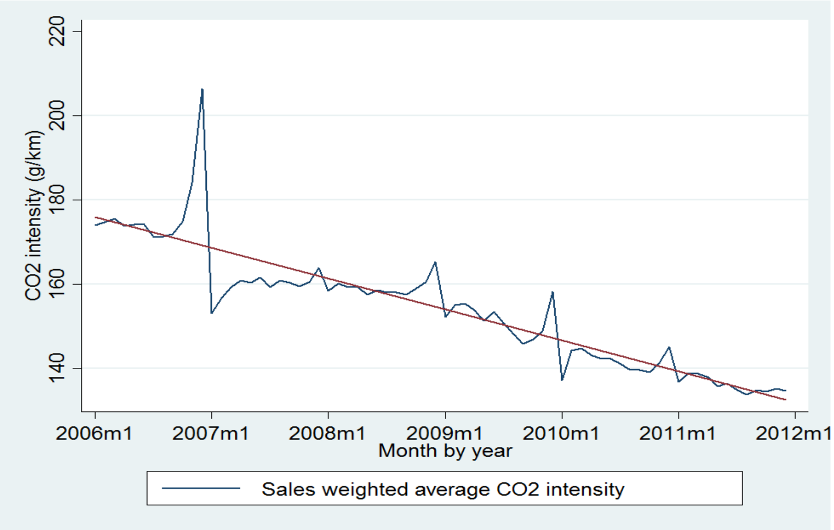

Fig. 3. Monthly sales-weighted average CO_2 intensity of new vehicles in Norway, 2006-2011

Beyond the average, Fig. 4 displays the distributions of new car sales over emission groups. In Fig. 4(a), in the short term, the introduction of the new tax in 2007 raised the sales of vehicles with intensity less than 180 g/km and reduced sales of those with more than 180 g/km. The average intensity fell by about 10%, from 177 g/km to 159 g/km in 2007. Fig. 4(b) shows the longer-term development through 2011. Compared to 2006, the 2011 intensity has fallen by about 26%. Similar shifts are seen in more narrowly defined groups, for instance between types of Volkswagen's Golf model (Appendix Fig. B2). Although these graphs tell an important story, many factors may lie behind these movements, motivating our econometric model in subsequent sections of this paper, to identify the response to the Norwegian registration tax changes.

In Fig. 4, one may be concerned that thresholds of CO_2 tax create 'bunching' of CO_2 intensities. However, we check for this by calculating the ratio of sales below and above but near the thresholds (plus and minus 2 grams) and find no tendency to increased bunching (Appendix Fig. B1). This is

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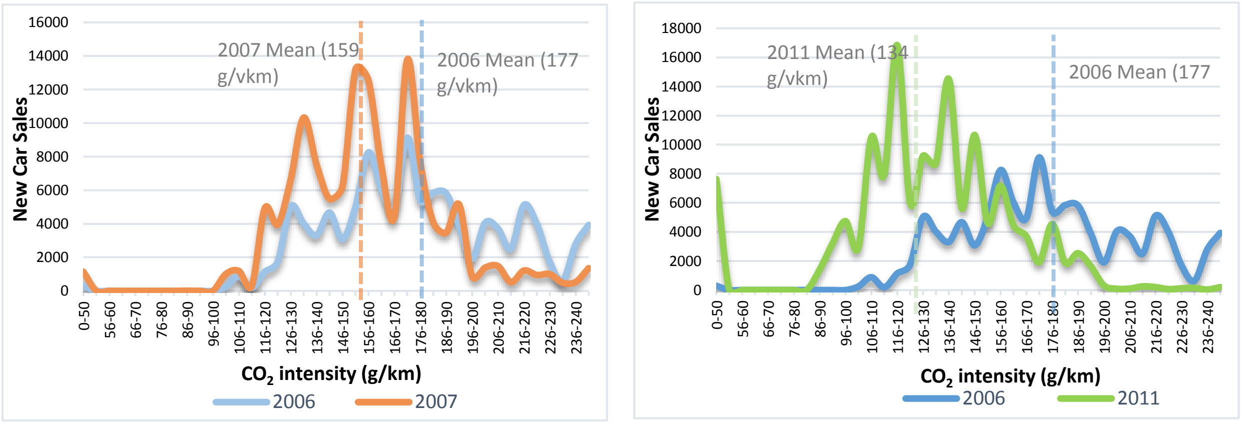
[5] The new CO_2 differentiated vehicle registration tax was proposed in a report and then presented at a public hearing with minimal fanfare.

plausibly because the tax liability is a continuous function, even though the slope changes. The fact that Norway is a small market for vehicle makers also helps us motivate the view that Norwegian policies to influence the prices of vehicle types and consumer choice in Norway, but do not to influence the supply of vehicles with different characteristics, or pretax international prices of vehicles.



(a) (b)

Fig. 4. Distribution of new passenger vehicles by CO_2 intensity in Norway.

Apart from the shift to low-emitting vehicles, there are two other important aspects behind the continuously decreasing trend of average CO_2 intensity. Firstly, since diesel-powered vehicle deliver the same driving with lower CO_2 emission, the share of diesel vehicles increases from 48% in 2006 to 76% in 2011 (Appendix Fig. B3). Second, in the short term, small changes can be made in vehicle materials, styling and weight to improve the fuel economy of a vehicle, while in the long term, technical improvements allow the same vehicle weight and engine power with lower emission rate (Appendix Fig. B5). Our study needs to take account for the possibility that these changes happen for reasons independent of Norwegian policies. Norwegian policies may determine the extent to which Norwegian buyers take advantage of the changes by lowering emissions rather than by raising requirements for speed, acceleration, weight, etc.

3. Economic concepts

From a welfare economic perspective, coordination of behavior for the purposes of providing a ‘global public good’ would be a tax (or tradable quotas) on CO_2 emissions, equivalent to fuel taxes that for each fuel are differentiated only by their CO_2 content. Thus, a CO_2 differentiated tax on the sale of new cars is at best 'second best'. But it may be seen in a pragmatic light as a sensible strategy in a transition phase, a way to instigate transformation of the stock of 'polluting durables' (cars) and technology to make the economy less dependent on CO_2. Unlike a Pigouvian tax that is placed on the quantity of CO_2 emissions, this CO_2 differentiated registration tax aims to influence car choice but not car usage. The registration tax may lead consumers choose to buy a smaller car that is relatively low emitting. The idea of taxing the CO_2 emission rate itself is that there may be many ways – not only being smaller – in which a car with lower emissions may satisfy a need or suit certain preferences.

As King (2007) estimates, choosing the lowest CO_2 emitters in any car market segment can make difference of about 25% to fuel efficiency and CO_2 intensity. To convey and discuss the underlying intuition of the vehicle registration tax, let us take a representative consumer for the whole new vehicle market. We restrict attention to the demand side, since the Norwegian market is too small to influence car manufacturers and the incidence of the tax falls on the buyer. In a simple model with two car types, the representative consumer chooses the quantities of two vehicle types, a high-emitting vehicle (Q_H) and a low-emitting vehicle (Q_L), with utility given by:

$$\boldsymbol{U = U(Q_H, Q_L)} \tag{1}$$

The consumer maximizes utility subject to a budget constraint:

$$\boldsymbol{M = C_H \times Q_H + C_L \times Q_L} \tag{2}$$

C_i (i=H or L) is the lifetime ownership cost[6]. A constant elasticity of substitution (CES) utility function could illustrate how the responsiveness to a CO_2 differentiated vehicle tax depends on the substitutability between the high emission vehicle and its 'substitute'. Abstracting from income effects and focusing on inter-vehicle substitution in this simple two-good case, we would expect

$$\boldsymbol{\frac{\partial Q_H}{\partial T_c} < 0 < \frac{\partial Q_L}{\partial T_c},} \tag{3}$$

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[6] $C_i = (P_{i,t_0} + T_{i,t_0}) + \sum_{t=0}^{T_i} \frac{M_{it}+act_{it}+(fp_t+ft_t)fe_iD_{it}}{(1+\rho)^t}$. $P_{i,t0}$ is the price of a vehicle before vehicle registration tax at the purchasing moment t_0. $T_{i,t0}$ is the Vehicle Registration Tax liability of a vehicle i at the purchasing moment t_0. $P_{i,t0}$ + $vrt_{i,t0}$ is the price consumer pays for a car. M_{it} is the maintenance cost. act_{it} is the annual circulation tax. D_{it} is the total distance derived. ρ is the discount rate. fp_t is the pretax fuel price and ft_t is the fuel tax. fe_i is the fuel economy of a vehicle i.

A tax T_c taxing high-emitting vehicles more than low-emitting vehicles (This could be a feebate taxing high-emitting vehicles while subsidizing low-emitting vehicles) raises the sales for the low-emitting vehicles but reducing the sales for the high-emitting vehicles. Greater the sales change are, higher the elasticity of substitution is (generally, the elasticity is the absolute value of the own- and cross-price elasticities). There is a possibility that both types of vehicles experience reductions in sales and low-emitting vehicle has a relatively smaller reduction due to the substitution.

Our multiple vehicle case is different from this two-vehicle case. This is best seen as we shift focus from the consumers to vehicle types. For a rising CO_2 based tax, most vehicle types will lose demand to less-emitting vehicles, but also gain some demand from higher-emitting vehicles. Indeed, one special case for the response could be all types lose as much demand as they gain, except the most high-emitting type which only loses and the most low-emitting vehicle which only gains. In fact, from an environmental perspective, it is the total effect on average CO_2 intensity that matters. Most importantly, the logic that we will take from this simplistic case is that for a heterogenous range of products (vehicles) may have many ‘substitutes’. For most vehicle types, we can imagine such substitutes will exist that are more highly emitting, equally emitting, or less. We cannot say in advance that we know for a given vehicle type which vehicle types represent its substitutes, even though we may have ideas. This, of course, will influence our strategy when we try to estimate the responsiveness to the CO_2 tax reforms.

4. Econometric approach

This paper aims to estimate the effect of the vehicle registration tax on the composition of new car sales (registrations) in Norway.

Cars represent a heterogeneous range of products that are differentiated in many quality dimensions. When CO_2 intensity becomes more expensive, some of the other quality dimensions also become more expensive to deliver, leading consumers to shift to other vehicle types or models (with less horsepower, for instance) or to accept the higher purchase cost. Our task is to establish a model of this responsiveness in car consumer demand and sales. In doing so, it has to be admitted that when a product is differentiated in many dimensions, we may lack prior ideas of which product types are close substitutes to others. In line with literature and industry terminology, we could use “segment”. As an example, vehicle types within the segment ‘subcompacts’ may be substitutes to each other. These vehicles may be closer substitutes to vehicle types in the ‘small car’ segment, than to the ‘large car’ or the ‘sports utility vehicle’ segments. In addition, within a more narrowly defined category called ‘model’ (Volkswagen Golf, for instance), we can assume that vehicle types with certain similar characteristics (e.g. engine sizes) are close substitutes. At last, one idea that we exploit is that substitutes will be found in a vehicle type’s ‘vicinity’ in terms of CO_2 intensity. As CO_2 intensity is itself associated with quality dimensions, ‘CO_2 neighborhoods’ may indicate substitutability. If a vehicle emitting 120 g/km increases in price, then less CO_2 intensive vehicles (118 g/km, for instance) might benefit from this with increased demands, whilst one with 122 g/km might lose. This assumption is not typical in the literature, but worth checking for us because of the policy experiment in relative prices and its motivation. Importantly, we shall exploit the fact that we have very finely defined product types in our data set. This has the implication that if we study changes in demand by vehicle type without limiting ourselves to specific assumptions of demand systems – making generous use of fixed effects – we can still recover important features of the responsiveness we are seeking.

Our data cover a period in which the CO_2 differentiated registration tax varies over time and affect all new vehicles. Therefore, a difference-in-difference approach are not able to identify tax effects on new vehicle demand appropriately. Similarly, methods making specific assumptions of substitution, such as multinomial logit or nested CES would be hard to justify because of the multiple quality dimensions and preference structures for such a range of products as ours. Such assumptions would to a great extent determine the results that we would rather want the data to inform us about.

To focus on the demand effects of tax changes and avoid the hazards of assumptions regarding to substitution between vehicle types. We use a linear equation for vehicle sales in Eq. (4). Later, we explore relaxations of the linearity assumption in Eq. (5). Our approach is tailored to fit the policy context as well as the available data. In particular, it controls for contemporaneous shocks in demand and supply with the help of fixed effects. The approach is in spirit with and informed by Klier and Linn (2015) and Chandra et al. (2010).

$$\boldsymbol{lnQ_{it} = \alpha\, T_{it} + \beta\, FC_{it} + \gamma_{jt} + \delta_i + \varepsilon_{it}} \tag{4}$$

In Eq. (4), the dependent variable is the number of new vehicles of type *i* registered at time *t*, in logarithms. The registration tax $\boldsymbol{T_{it}}$ is one of the independent variables, the one of greatest interest in fact. The tax effect on sales that we estimate subsumes the impact of market responses that emerge due to changes in the new vehicle registration tax. The price is omitted in the regression. While we explore the tax effect through prices later in Eq. (6) and (7), we notice here that the vehicle registration tax may be less than completely passed through to consumers. In Eq.(4), $\boldsymbol{FC_{it}}$ is fuel costs (quarterly fuel price times fuel consumption per vehicle kilometer), which is not just of interest in itself, but also helpful in identifying the effects of the vehicle registration tax[7]. In Eq. (4), γ_{jt} is a model-year-quarter fixed effect, while δ_i is a vehicle type fixed effects. ε_{it} is an error term. Fixed effects are important in eliminating other shocks than those pertaining to the vehicle tax changes themselves.

We use log form of new vehicle sales to estimate responsiveness in percentage of sales. Because sales differ much among different vehicle types (and models). Sales changes in the percentage form can be an appropriate formulation when we look at changes over time associated with tax changes. A log form of the tax is not possible, since the tax can be zero or even negative (due to 'feebate'). Moreover, the relationship between log price and log tax is not linear.

Vehicle type is defined more narrowly than to a unique car model, by including fuel type (gasoline or diesel), engine power, engine size, weight and the CO_2 intensity. It is constructed from the original data (Table 1).

Table 1

Number of observations by aggregation level

	2006	2007	2008	2009	2010	2011
Car model	243	247	251	256	253	239
Vehicle type	2758	2666	2777	2792	2826	2658

Around 100 000 new vehicles are sold and registered annually, distributed over about 2800 vehicle types that belong to about 240 vehicle models . The national level of aggregation matches the level of policy interventions in Norway. Fuel taxes, registration taxes, fuel price and car price data all are national. Time is defined by year and quarter. In our main estimations, data covers the period from 2006 to 2011, and during this period, no other relevant national polices are introduced/changed. After 2011, authorities introduce both a NOx element in the vehicle registration tax. Together with electric vehicle incentives, such vehicle policies are difficult to

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[7] Colinearity between registration tax and fuel cost is avoided as the latter includes quarterly fuel price, whereas the vehicle registration tax is modified only by year (in January).

represent (or control for) considering the data we have. Therefore, our main estimates are done with the data set ending 2011 (when few electric vehicles are purchased). Importantly, the quarter as time unit allows us to control for policy pre-announcement effects and also for the price effects of vehicle fuels.[8] Robustness checks will be done in section 5.2 where vehicle type is defined by more vehicle characteristics, yearly observations, etc.

T_{it} , the total vehicle registration tax, is the sum product of the value of vehicle characteristics and corresponding tax rates. Within the period from 2006 to 2011, the tax consists of three parts: weight-based tax, engine power-based tax and engine size-based tax, where the latter shifts to a CO_2-based tax in January 2007. The changes of the CO_2-based tax account for the majority of the total registration tax changes from 2006 to 2011. Our focus on the sum of the taxes has its main motivation in the policy experiment, which does not give us alternative shocks to the various elements in the tax changes, but at every occasion one shock. We notice that weight and engine power are highly positively correlated with CO_2 emissions. For a specific vehicle type with given characteristics, the sales response to a tax change should be the same irrespective of its 'origin'. According to Norwegian marketing laws, listed prices include all applicable taxes, and buyers will not be informed about or interested in the various tax components.

Fuel prices significantly affect vehicle purchases (Kiler and Linn, 2013; Eskeland and Feyzioglu, 1997). We include fuel cost per kilometer, FC_{it}. It is calculated by fuel price (NOK/L) and fuel consumption (L/km), using present fuel prices when the vehicle is purchased as a proxy for expected fuel prices. Other than fuel cost, we do not include any annual costs. Those costs are assumed invariant for all car specifications within the same model. For example, annual circulation tax only differs little depending on the filter installation.

Two fixed effects are included. A time invariant fixed effect δ_i, is defined at the level of vehicle type (a unique car model, but then further separated into 'type' by engine size, engine power, weight, and CO_2 intensity). The model-year-quarter fixed effect, γ_{jt} is defined by the interaction between a unique model j and year-quarter t. δ_i controls for all characteristics of vehicles that do not vary over time. γ_{jt} controls for shocks at the model level, both to demand and supply, for example economic crisis in 2008 or exchange rate movements, policy pre-announcement effects,

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[8] The preannouncement effects refer to consumers responding to the future tax change. In the last quarter of each year (2006 in particular), average CO_2 intensity has a peak (Fig. 3).

and changes of unobserved vehicle model characteristics, including technological change, policies in Europe, etc. These fixed effects also enable us to control for national preferences for particular car models over time. They will pick up such broad phenomena as model shifts due to the effect of income growth in Norway.

Our approach allows us to take account of observable and unobservable aspects of policies, model changes and within model changes. An individual car model may be produced for a decade or more, while the manufacturer tends to redesign passenger vehicles and introduce new versions at the start of the calendar year in the Europe (Klier and Linn, 2015). As we control for vehicle make, model, fuel type, fuel economy, weight and engine characteristics, year-to-year physical changes are minor. But these changes will be picked up by our 'vehicle type' definition in our characteristics, or otherwise by our fixed effects. Secondly, while Norway does not have a fuel economy standard, within EU, a CO_2 emission standard is implemented on vehicle manufacturers[9]. The standard as well as other drivers of technological change and car supply may affect the fuel economy/CO_2 intensity of new vehicles supplied in the Norwegian market. In our approach, both will be captured by the fixed effects for model that entails quarters. Our responsiveness to tax changes in Norway is estimated considering such developments exogenously given.

Although the model-year-quarter fixed effects are useful for identifying the tax effect, they absorb some of the data variation and leave only the within-model (between vehicle type) responses to identify our parameter α. These within model variations account for a significant share of the overall consumer purchase response. Vehicle types vary a lot within car model (Table 1). On average, there are 11-15 specifications within one vehicle model, so consumers have many closely related vehicle options. For a robustness test, we also use segment-year-quarter fixed effects. These fixed effects include substitutions between models in our responsiveness coefficient since there are 11 segments, thus giving much broader groups than the about 240 car models. Apart from this, we also define broader groups, 'neighborhood' in the CO_2 intensity dimension in our fix effects. Compared to groups depending on segments and 'CO_2 neighborhood' that are subjectively defined, car model is naturally grouped by physical features and production strategies by manufacturers. The model-year-quarter fixed effects provides balanced estimation in terms of controlling for

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[9] The 2009 regulation set a 2015 target of 130 g/km for the fleet average of all manufacturers combined. Individual manufacturers were allowed a higher CO_2 emission value, depending on the average vehicle weight of their fleet (Mock, 2014).

demand/supply shocks and retaining variation for estimation. In our results section, we report the variation remaining with our ‘generous’ fixed effects is sufficient to identify the tax responsiveness. Briefly, based on a priori ground and alternative formulations, the regression Eq. (4) can use the within model changes to identify the causal effect of the tax changes on new vehicle registrations.

The coefficient α represents the percentage change of vehicle type sales with respect to its own vehicle tax change. Our fixed effects approach means that our estimated alfa relies only on within model variations, reflecting that this is both sufficient for estimation and necessary to control for shocks other than the tax changes. Estimates that take specific account of relative tax changes are included in section 5.2.2.

In Eq. (5), an interaction term is included to allow a difference in slope α, either for each vehicle segment k, or similarly for different groupings of intensity, or simply with a quadratic term for the tax.

$$\boldsymbol{lnQ_{it} = \beta FC_{it} + \alpha_1 T_{it} + \alpha_2 T_{it} * g_k + \gamma_{jt} + \delta_i + \varepsilon_{it}} \qquad \textbf{(5)}$$

An important additional inquiry is to look into how the effect of the tax is conveyed through the market price to vehicle sales. A reason why we do not let this be our main analysis is that the price data has weaknesses. First, the price data is incomplete. It reduces the number of observations largely due to mismatches in the combination of the vehicle registration data and vehicle price data through vehicle characteristics. Second, it represents list price and therefore will suffer from endogeneity bias as well as inaccurately reflect actual transaction prices. It is well know that increase in demand for vehicle cause price of vehicle increase, resulting in a spurious correlation between price and the regression error and bias in the estimates. Our instrumental variables approach regresses vehicle registrations (Q_{it}) on vehicle price (P_{it}).

This addresses the endogeneity issue as the registration tax is used as an instrumental variable for the price[10]. The vehicle registration tax accounts for a significant share of vehicle sales price, and the tax is highly predictive of vehicle prices since both are based on vehicle characteristics. The registration tax is independent from the new vehicle markets in that vehicles have multiple alternatives in types/models and consumer does not buy many vehicles in store for the future use.

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[10] There is a tradition to instrument for gasoline prices using gasline taxes in order to estimate the responsiveness of gasoline consumption (Coglianese et al., 2015).

Therefore, we adopt a two stage least squares (2SLS) method to for instrumental variables (IV) estimates in Eq. (6) and Eq. (7).

First stage: $$\boldsymbol{P_{it} = \alpha_1\, T_{it} + \beta_1\, FC_{it} + \gamma_{jt} + \delta_i + \varepsilon_{it}} \quad \textbf{(6)}$$

Second stage: $$\boldsymbol{lnQ_{it} = \alpha_2\, P_{it} + \beta_2\, FC_{it} + \gamma_{jt} + \delta_i + \varepsilon_{it}} \quad \textbf{(7)}$$

As a result, the effect of tax on vehicle registration is $\alpha_1 \times \alpha_2$. We use this approach to discuss our main results and the interpretation of the results from Eq. (4). This IV approach has another important advantage, as is discussed by Gavrilova, et al. (2015) for payroll taxation effects on labor demand through wage. The approach helps to understand the tax effect on vehicle registrations through price mechanism. For instance, if there is no response to tax changes in vehicle sales, our reduced form approach is not be able to distinguish between two possibilities of 'no pass through of the tax to the price' and 'no price responsiveness in demand'. Further interpretations require caution and need to be discussed in light of the fixed effects and the limitations of price dataset. Pricing decisions are made separately by car companies while the tax reforms are instituted uniformly. Our model-year-quarter fixed effects fit the estimation of the tax effect rather than the price effect. Moreover, these limited vehicle characteristics lead to a strong correlation between merging price data and defining individual vehicle types. In this case, large variation in price data may be absorbed by vehicle fixed effects.

5. Results and discussions

5.1 Results from main specifications

Table 2 reports the coefficients of the registration tax and vehicle fuel cost from Eq. (4). The first row presents the estimated tax coefficients, followed by robust standard errors. All the estimated tax coefficients are statistically significant, and with the expected sign. The second row is the coefficients of fuel costs that are also significant and with the expected sign.

The tax coefficient in model 1 indicates that a tax increase of thousand NOK (about USD 120, about a quarter of a percent of the price of a mid-size car) reduces vehicle sales (for a given vehicle type) by 1.26%. These coefficients do represent very 'price sensitive demands', showing that typically any vehicle type has close substitutes.

The fuel cost coefficient indicates that an increase of one NOK in cost per km (about 112000 NOK per year) reduces demand by 94%. To compare the size of the fuel cost sensitivity parameter with the tax sensitivity parameter, we use the annual cost increase of 15 thousand NOK (15 thousand vehicle kilometers is a Norwegian average mileage) and discount it at ten percent over 12 year expected lifetime. Then, the estimated fuel cost sensitivity translates into about ¾ of the tax sensitivity, indicating that buyers discount future fuel costs with a somewhat higher discount rate or a lower expected lifetime.

All results are based on data for new passenger vehicles registered in the years 2006-2011. We run four model specifications, all of which include vehicle type fixed effects that account for characteristics and preferences that are constant for vehicle types. In addition to vehicle type fixed effects, the first specification includes the model-year-quarter fixed effects. These pick up and eliminate shocks down to quarter and model. In model 2, we replace these finely disaggregated fixed effects with segment-year-quarter fixed effect, much less finely disaggregated. In model 3, we leave behind specifications such as model and type, and rather include fixed effects for a close ‘neighborhood’ of vehicle types with similar CO_2 intensities. In model 4 we include model-year-quarter fixed effects and county-model fixed effects. The first three specifications are based on national level observations. Model 4, in contrast, is based on more observations since vehicle data is disaggregated to county level. There are 20 counties in Norway.

An increase in the vehicle registration tax reduces vehicle registrations in a significant manner in all four specifications. Across models, with the exception of model 2, the tax coefficients remains stable, varying around -0.0126 from -0.014 to -0.011. In model 2, the tax effect on vehicle registration is smaller, probably reflecting that the broader segment-fixed effects control insufficiently for demand and supply shocks that to some extent offset tax effects on vehicle registrations. We prefer the first specification (Model 1) which includes the model-year-quarter fixed effects as explained in section 3. Model 1 also has the best fit in terms of R^2.

Table 2

Estimates of the registration tax effects on registrations of new passenger vehicle in Norway.

	(1)	(2)	(3)	(4)
Tax	-0.0126***	-0.0055***	-0.0142***	-0.011***
	(0.0012)	(0.0008)	(0.0031)	(0.000)
Fuel cost	-0.9448*	-1.2653 ***	-1.3929	-1.05***
	(0.4346)	(0.3617)	(0.7869)	(0.138)
Vehicle type FEs	Yes	Yes	Yes	Yes
County-model FEs				Yes
Model-year-quarter FEs	Yes			Yes
Segment-year-quarter FEs		Yes		
CO_2-neighborhood-year-quarter FEs			Yes	
Number of observations	34552	35585	33295	197887
Adjusted R^2	0.65	0.62	0.63	0.56

Note: *p<0.05, **p<0.01, ***p<0.001. For readability, tax is divided by 1000.

Estimating tax effects in the different vehicle groups

In Table 3, we introduce some variations allowing for tax effects to vary across the range of vehicles. In Model 1, we give the tax itself a possibly nonlinear role by introducing a quadratic terms (the tax squared). In model 2, vehicles are grouped according to the brackets of the CO_2 tax rates[11]. In model 3, the vehicles are grouped into segments in the original dataset (9 segments from mini through SUV). For both model 2 and 3, the coefficient estimates represent a tax coefficient additive to the tax coefficient on the top. All three models reflect more details than the overall average tax effects in Table 2. The marginal effect of a 1000 NOK tax is lower for the heavier vehicles. Since for vehicles that are more CO_2 intensive and more heavily taxed, a 1000 NOK tax increase represents a smaller cost in percentage.

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[11] Emission groups: (0-50 g/km), (51-120 g/km), (121-140 g/km), (141-160 g/km), (161-180 g/km), (181-200 g/km), (201-220 g/km), (221-250 g/km), (>251 g/km)

Table 3

Estimation of tax effects: different vehicle groups

	(1)	(2)	(3)
Tax	-0.0222***	-0.0668***	-0.1399***
	(0.0018)	(0.0085)	(0.02859)
Fuel cost	-1.0778*	-0.8899***	-0.9940*
	(0.4332)	(0.4325)	(0.4336)
Tax_square	0.00001***		
	(0.0000)		
Group 2		0.0344***	0.0978***
		(0.0098)	(0.0302)
Group 3		0.0316***	0.1268***
		(0.0094)	(0.02875)
Group 4		0.0441***	0.1222***
		(0.0108)	(0.02868)
Group 5		0.0402***	0.1233***
		(0.0095)	(0.02871)
Group 6		0.05828***	0.1341***
		(0.0089)	(0.02864)
Group 7		0.0578***	0.1408***
		(0.0087)	(0.02939)
Group 8		0.0616***	0.1416***
		(0.0087)	(0.02899)
Group 9		0.0645***	0.1428***
		(0.0086)	(0.02874)
Observations	34552	34552	34552
Adjusted R^2	0.65	0.65	0.65

Note: The first group in each division serves as the base group.

Exploring how the tax works through the vehicle price with two stage least squares

The registration tax with its CO_2 element has its effect on vehicle registrations through its influences on the vehicle's price. We study both how the tax influences the vehicle price *and* how the price influences demand. Table 4 presents the results for Eq.6 and Eq.7 using an instrumental variables approach. The first column (First stage) shows an estimated effect of a tax increase on the vehicle's price of 0.885 with a small standard error 0.0163. This indicates that 89% of tax variations are passed to buyers[12]. In other words, a small part of the tax change (11%) is borne by manufacturers. This small effect works against the registration tax's objective of enticing demand reductions, but it may give incentives to manufacturers to find ways to deliver cars with less CO_2. The second column shows that the estimated effect of the vehicle's price on demand is -0.0179 with a standard error 0.0025[13]. Combining the two columns, the effect of the tax on vehicle registrations is the product of the coefficients for tax and price, which is 0.0158. It is quite close to the estimated coefficients we obtained in the direct approaches of Table 2 for Eq. (4), indicating that our reduced sample for the IV model does not involve important biases.

The IV approach has the advantage of being more economically intuitive and meaningful, and addresses endogeneity. But in the end we are mostly interested in the tax effect, and are concerned about the reductions in observations and the quality of the price data. For the reasons, we will concentrate on direct estimates, not the two-stage (IV) ones, in our further analysis and discussion.

Table 4

Estimation of tax effects: instrumental variable

	First stage	Second stage
Tax	0.8846^{***}	
	(0.0163)	
Fuel cost	-4.4678	-1.3773^{*}
	(3.8363)	(0.6473)
Price		-0.0179^{***}
		(0.0025)
Number of observations	15425	15425
Adjusted R^2	0.99	0.81

Note: *p<0.05, **p<0.01, ***p<0.001. For readability, tax is divided by 1000.

5.2 Robustness analysis

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[12] Simply regressing prices changes on tax changes without model-year-quarter fixed effects, we get similar estimate for the tax coefficient.

[13] The price effect may be somehow large. But it is explained in the section 4.

5.2.1 Aggregation

Aggregating data to have annual observations rather than quarterly, model 1 in Table 5 shows the results for Eq. (4). The estimated coefficient for the tax, minus 0.0158 reflects a slightly greater responsiveness than our main result (-0.0126) in Table 2. Especially to control for external factors such as the preannouncement effects but include more data variation, we prefer to focus on the formulation with quarterly observations.

Model 2 in Table 5 shows the results for Eq. (4), but allows vehicle type to be defined by additional characteristics, such as body, transmission and number of doors. With greater number of observations resulting from more detailed car specifications, standard error are reduced. The coefficient estimate is similar to the results in the Table 2.

In model 3 in Table 5, we include all years, from 2006 to 2014. When our main regressions have not used 2012 through 2014, two reasons are important. Firstly, we lack NOx emission rate to calculate the NOx tax introduced in 2012[14]. Second, starting 2012, the boom of electric vehicle contributes significantly to declining of average CO_2 intensity. Electric vehicles are subject to exemptions and additional supports that are not covered in our data. In model 3, the estimated tax coefficient is a little larger in absolute value than what we have in Table 2. This may reflect a bias due to omitted coverage of the additional incentives for electric vehicle.

Table 5

Data aggregation

	Yearly (1)	Detailed Specification (2)	All years (3)
Tax	-0.015^{***}	-0.013^{***}	-0.016^{***}
	(0.002)	(0.001)	(0.001)
Fuel cost	-2.780^{*}	-0.942^{*}	-1.18^{***}
	(1.378)	(0.432)	(0.370)
R^2	0.56	0.65	0.66
Observations	11980	35002	54963

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[14] We use standard NO_x emission rates for fuels and fuel consumption data, to obtain an approximate NO_x rate of vehicles We do not consider the variation of engines across car models and the installations of different filters that can largely affect NO_x emission rates.

5.2.2 Alternative specifications

We assess the robustness of our regression results by respecifying dependent as well as independent variables. The first model in Table 6 addresses the size of new vehicle market, modeling the vehicle type's share in the market rather than the number of vehicles sold. The tax coefficient is almost the same as Table 2[15].

We want to check the relevance of relative tax changes to our estimates. The relative tax change between cars and own tax change are closely related for comparable vehicles since they are under the same tax structure based on vehicle characteristics. Generally, this issue is addressed with our fixed effects. But in Model 2, Table 6, we allow vehicle demand to depend also on the taxes of other cars that may be close substitutes. We include two additional independent variables: *tax_left* is the average registration tax for all vehicles that are, at most, 2 g/km less CO_2 intensive than the vehicle type in question, and *tax_right* is the average registration tax for vehicles at most 2 g/km more CO_2 intensive. As shown in Table 6, the estimated relative tax coefficients are small and not significantly different from zero. More importantly, the estimated own tax estimate is unchanged. Therefore, using the more straightforward approach of fixed effects, rather than relying on assumptions of neighborhoods of structure with assumptions of substitutes, is supported in light of our practical research objectives.

Thirdly, the vehicle type fixed effects pick up preferences for vehicles with different characteristics that are constant. But preferences for characteristics can change over time. Model 3 in Table 6 includes a trend variable interacting with fuel type (diesel and gasoline) and Model 4 for engine power. Both can be seen to represent a trend in consumer preferences or technological change. In the latter case, if we allow a trend in power (wealth and preferences might make us want more), then responsiveness to the tax in absolute value is raised.

Lastly, the registration tax rate makes discontinuous jumps at the cutoffs at 120g/km, 140g/km, 180g/km and 250g/km (Fig. 1). Consumers thus may have stronger economic incentives to shift their purchases from vehicles just around the cutoffs. Regression (not shown) using only observations near cutoffs yields estimated tax coefficients almost three times larger in absolute value than the one (1.26%) in Table 2. When we drop the observations near the cutoffs (within ±

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[15] This is not too surprising, given that our 'vehicle type' is finely defined.

2g/km), we can see in Model 5 of Table 6 that the estimated tax coefficient is still close to the one in Table 2, indicating that the small share of vehicles around the cutoffs do not bias our results.

Table 6

Omitted variables

	Sales share (1)	Relative taxes (2)	Fuel type (3)	Engine power (4)	Cut-offs Excluded (5)
Tax	-0.013***	-0.012***	-0.012***	-0.019***	-0.012***
	(0.001)	(0.001)	(0.012)	(0.001)	(0.003)
Fuel cost	-0.945*	-0.924*	-1.579***	-1.132**	-1.041*
	(0.435)	(0.434)	(0.444)	(0.378)	(0.456)
Tax_left		0.000			
		(0.000)			
Tax_right		-0.001			
		(0.000)			
R^2	0.65	0.65	0.65	0.65	0.65
Observations	34552	34552	34552	34552	30883

6. Implications

In this section, we do three things to understand the nature of our findings quantitatively. First, we use our estimated model to disentangle the reductions in CO_2 intensities; what part is due to the tax changes? Second, we use it to estimate reductions in CO_2 intensities when the demand system is exposed to realistic reforms, i.e. increased CO_2 prices, indicated by the CO_2 differentiated registration tax. In the following two sections, we use the tax coefficient (-0.0126) from the Model 1 in Table 2.

6.1 ***Disentangling the role of the tax reform in the declining CO_2 intensities historically***

We use the estimated tax coefficient to calculate vehicle sales changes corresponding to changes of the CO_2 differentiated registration tax, keeping other exogenous factors unchanged. The average CO_2 intensity of new vehicle sales was 177.76 g/km in 2006 and 159.63 g/km in 2007, while for 2007 the projected mean (due only to the CO_2 tax reform) was 163.37 g/km. Thus, 14.39 grams of the 18.14 grams reduction, or 79%, was due to the CO_2 tax change. Other factors, such as income changes, preferences, European and other standards and technological changes, account for the remaining 21%. In other words, the introduction of CO_2 differentiated vehicle registration tax explained a large part of the reduction of average CO_2 intensity from 2006 to 2007 in Norway.

6.2 *A CO_2 elasticity estimate for new vehicle sales*

Here, we investigate the response in CO_2 intensity to CO_2 price changes that are indicated by the CO_2 tax changes. Using a CO_2 price allows us to abstract from the issues in combining fees and rebates. Choosing 2009 (first year of the feebate implementation) as a baseline, we simulate a rise in the CO_2 price by 50% and calculate the changes in tax, sales and thereby emission intensities. Results are listed by increasing intensity in the Table 7. The average CO_2 intensity of total car fleet is reduced by 2.74% and the sales-weighted average CO_2 price is increased by 48.41, resulting in an elasticity of CO_2 intensity with respect to the CO_2 price of minus 0.06. This result is very close to the estimates in the research by Michielsen, et al. (2015) based on European historical data. However, our estimates provide more details in the composition of new vehicles. Furthermore, in Table 7, we can notice that average CO_2 intensity are more sensitive to the change of CO_2 price in the heavier segments, and that the overall reduction is about equally shared by within-segment reductions and between-segment changes. Comparing the lower two rows, the elasticity of minus 3 percent is the average of the elasticities within segments, and minus 6 percent includes sales changes between segments.

An elasticity of CO_2 intensities with respect to CO_2 price of minus 0.06 may appear small. However, it appears both reasonable and plausible if we notice that the CO_2 tax as a share of the vehicle price for a ‘mean’ vehicle is about 8 percent. Thus, the car price change in percentage is about a tenth of the CO_2 price increase in percentage, so the elasticity of CO_2 intensities with respect to car prices is about eight times minus 0.06, or about minus 0.5. This means that CO_2 price increases that raise car prices by ten percent will reduce emission intensities by about five percent.

Table 7

The elasticity of average CO_2 intensity to the average CO_2 based registration tax by segments

	CO_2 intensity before changes	CO_2 intensity after changes	CO_2 price before changes	CO_2 price after changes	Growth rate of intensity	Growth rate of price	Elasticity
Mini	112.74	112.38	500.36	750.49	-0.33%	49.99%	-0.01
Small	127.97	127.16	502.00	752.80	-0.64%	49.96%	-0.01
Compact	135.84	134.13	504.73	756.06	-1.25%	49.79%	-0.03
Medium	152.73	151.18	509.34	762.10	-1.02%	49.62%	-0.02
Sports	164.72	162.09	521.30	773.09	-1.60%	48.30%	-0.03
Large	169.63	166.45	532.32	788.10	-1.87%	48.05%	-0.04
Multi-purpose	170.09	166.82	528.69	780.56	-1.93%	47.64%	-0.04
SUV	181.04	177.62	546.75	804.99	-1.89%	47.23%	-0.04
Luxury	198.11	193.39	593.85	860.99	-2.38%	44.99%	-0.05
Others	217.90	203.67	676.79	941.97	-6.53%	39.18%	-0.17
Average[16]	151.14	149.02	517.72	771.10	1.33%	49.01%	-0.03
Total fleet	151.14	146.99	517.72	768.34	-2.74%	48.41%	-0.06

Note: CO_2 intensity and CO_2 price here are sales weighted average.

In Fig. 5, we present the reductions in emission intensities within segments with the changes in demand between segments in the direction of arrows from gray points (before tax change) to corresponding black points (after tax change). Important changes – such as exogenous technological change – are eliminated through the fixed effects, so Fig. 5 shows us only the changes that are due to the CO_2 tax changes[17]. Heavy and large vehicles such as luxury cars have the highest CO_2 intensity. Buyers of such vehicles can respond to higher CO_2 taxes either by choosing lower emitting cars in the original segment or by shifting purchases to vehicles in lighter segments. Buyers of cars in the middle segments reduce their emission intensities within the segments, but the sales of these segments themselves are about unchanged (they win about as much from heavier

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[16] The average value of above all segments is 0.028 based on the vehicle sales before tax change. If we use the vehicle sales data after tax change for calculating average value, it is 0.026.

[17] One may be surprised by our commitment to simplicity, even in Table 7 and Fig. 5. Our elasticity estimates turn out to be the same (minus 6% for the tax elasticity and minus 50% for the elasticity with respect to car prices when these change due to a CO_2 tax increase).

segments as they lose to lighter). Lighter segments experience rising sales and modest emission reductions. As a result, lighter and smaller cars (e.g. sports cars) have slighter response to CO_2 price change than larger and heavier cars (e.g. luxury cars). Light segments such as mini, small, compact and medium cars increase their sales, as indicated by Eq. (3), as vehicle purchases shifts from high-emitting vehicles to low-emitting vehicles.

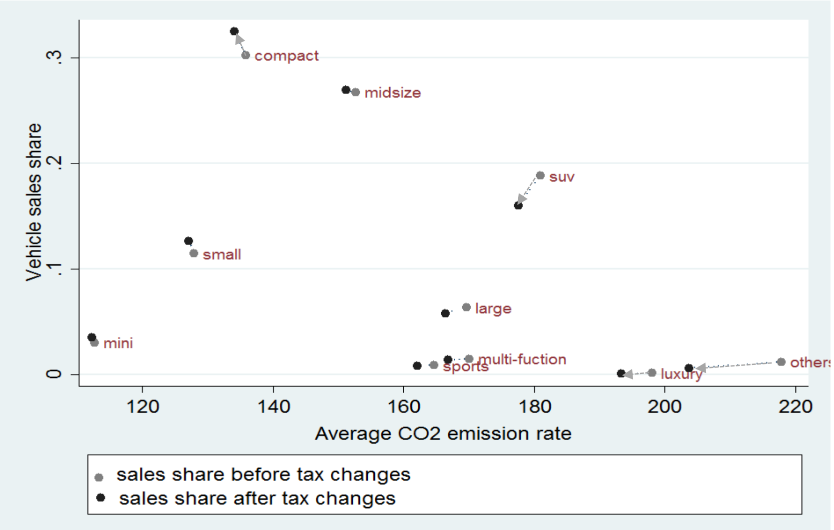

Fig. 5. Average CO_2 intensity and vehicle sales share by segments before and after tax changes

7. Conclusion

There is a good prima facie argument that a fuel tax is a first-best instrument that can and should be used for emission reduction. In light of this principle, fuel economy standards (Like those in EU, or CAFE in USA) and the CO_2 based vehicle taxes applied to cars – analyzed here - are not obvious as policy recommendations.

Nevertheless, policy makers may want a policy instrument that works on CO_2 intensities in the vehicle stock via new car sales, and thus look to standards, tradable quotas, or taxes that change the relative prices in favor of vehicles with lower CO_2 intensities. As a small country without a car industry, Norway changes the registration tax for new cars by heavily taxing CO_2 per vehicle kilometer. It provides a political experiment worth studying. The responsiveness of car purchases – and the responsiveness in CO_2 intensities in the car fleet – is of interest whether the objective is emission reductions or energy security.

More generally, we may think about reductions in emissions or energy use in settings where the composition of assets (vehicles) and their use represent separate windows for policy intervention. There are good reasons to assume that first-best instruments such as fuel taxes would cost-effectively both modify the car fleet through new car sales – studied here - and economize on driving. It is clear that if instruments such as CO_2 based vehicle registration tax on new car sales are used to influence the car fleet composition, there is also a need for user cost instruments, such as fuel taxes to influence the use of cars[18].

This paper analyses the effects of the CO_2 differentiated tax on vehicle registration (new car sales) and the average CO_2 intensity of the new vehicle fleet in Norway. The econometric analysis includes vehicle type fixed effects and model-quarter fixed effects to control for the potential confounding effects through vehicle characteristics, time effects, policy pre-announcement effects, technology improvements and consumer preferences. We perform numerous reformulations to examine alternative functional forms, variable inclusions and aggregations which allow us to be informed by the past policy reforms. We use a simple model for the practical purpose of quantifying the effects of prospective policies.

The estimates in the regressions imply that 1000NOK tax increase (USD 120, or about a quarter of a percent of the value for a midsize car) for one vehicle type is associated with a sales reduction of 1.26% to 1.58%. This result is significant and robust. We conclude that a large part of the reduction in the sales-weighted average CO_2 intensity in Norway since 2006 is attributed to the introduction and increase in the CO_2 differentiated registration tax. Viewing the rising tax as a rising CO_2 price, a 1% increase in the CO_2 price is associated with a 0.06% reduction of average CO_2 intensity. Translating this effect into one that relates to new car prices, for a typical 'median' car price and its CO_2 tax share, this implies a CO_2 elasticity with respect to new car prices of about minus 50% (when the car price changes due to CO_2 tax increase). Another finding worth mentioning is that even with the high taxation of CO_2 in the Norwegian case, car buyers remain sensitive to fuel costs,

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[18] A chain of arguments is in favor of sensible policy instrument combinations. Khan (1986) demonstrates – as expected a priori – that also for used cars, higher fuel prices change relative car prices, reducing the value of the less fuel economic ones. Together with Manski (1983)'s model of scrappage (cars are scrapped when repair costs exceed repaired car's value), fuel taxes embodying emissions thus changes both the car fleets' usage, and accelerate scrappage of the least fuel efficient. As argued by Eskeland and Mideksa (2008), a role for standards may be the greater commitment in policy. Accelerating asset renewal may play a role in political economy, since resistance to fuel taxes is reduced as the fuel economy embodied in the stock of assets (cars) is rising.

even in a setting where government fairly strongly has given consumers other reasons to seek fuel-efficient vehicles.

Our analysis finds that the declining average CO_2 intensity represents a consistent and significant purchase shift towards vehicles with lower CO_2 emissions, driven in majority by Norway's introduction and raising of its CO_2 differentiated vehicle registration tax.

One should note that total emissions depend also on the total number of vehicles and kilometers driven. Vehicle sales may rise for many reasons – and so may driving – but driving will be stimulated by the fact that people are induced to hold cars with lower user cost (higher fuel efficiency). In Norway, policies towards driving should also include geographical and time dependent factors, such as congestion and local air pollution. Toll rings in cities like Oslo and Bergen can be used to differentiate discouragement of driving by vehicle characteristics, and present approaches giving full exemption for electric cars should probably be further nuanced to reflect further differentiation of air quality impact, and more general discouragement to congestion.

Important issues that we have not looked into here are lifecycle assessments and other questions of indirect emissions. Emissions in the transport sector are then addressed at the source only, which is not unusual and entails strengths and weaknesses. It considers a vehicle as zero emitting both locally and globally if its tailpipe is clean. It abstracts from pre-tailpipe emissions in the energy carrier (well to tank from diesel and gasoline, coal fired electricity generation for electric vehicles) as well as emissions in the manufacturing and recycling of cars and batteries[19]. In addition, there is gap of emission intensities between real world on-road and official laboratory tests. This is against excessive use of vehicle taxes based on the emission intensities. Much analysis has been done and remains to be done in these areas, but are beyond the scope of this research.

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[19] Relevant arguments are made by Eskeland (2012), in favor of drawing this cutoff at the tailpipe both in analysis and in policy.

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Appendix A. Data description

The primary variables are registrations of new private passenger vehicle, vehicle price, fuel price and vehicle registration tax. The data span 2006-2014 for Norway. The summary statistics are presented in the Table A1.

New vehicle registration and characteristics data

The monthly registration data of new passenger vehicles from 2006 to 2014 is provided by Norwegian Road Federation (OFVAS). The data covers all municipalities/county in Norway. The data is structured by brand, model, segment, body, engine fuel type, engine power, engine size, transmission type, number of doors, fuel economy and weight.

Vehicle price

The yearly vehicle price data from 2006 to 2014 is collected from the main professional car importers in Norway by Norwegian Road Federation (OFVAS). The sales price include all taxes. The dataset also contains detailed vehicle characteristics, such as brand, model, engine power and weight. The vehicle price data is merged with the registration data by vehicle characteristics.

Fuel price

The fuel prices for both diesel and gasoline are collected from Statistics Norway (SSB). The national fuel prices are presented in NOK by month from 2006 to 2014 (Appendix Fig. A1). Quarterly and yearly fuel prices are obtained by averaging monthly price, including fuel taxes.

Vehicle registration tax

The registration tax rates for new passenger cars are collected from the National Budget (2006-2014) by Norwegian Ministry of Finance. It includes the taxes based on weight, engine power, engine size, CO_2 emission and NO_x emission (Table A2).

Table A1

Summary statistics for regression data

Variable	N	Mean	Std.Dev.	Min	Max
Vehicle sales	37955	18.712	49.912	1	1283
CO_2	37955	169.110	40.437	59	448
Weight	37955	1452.8	295.462	701	4030
Engine power	37955	102.028	39.996	33	476
Engine size	37955	1933.557	570.027	698	7011
CO_2 differentiated vehicle registration tax	37955	30021.46	42078.4	-37149	564082
Total vehicle registration tax	37955	147966.8	125026.1	8517.067	1378867
Gasoline price	37955	12.342	0.964	10.833	14.267
Diesel price	37955	11.414	1.123	9.9	13.233
Fuel cost (NOK/km)	37955	0.788	0.203	0.318	2.314
Vehicle price	17313	363867.8	226469.3	101782.4	3446852

Note: For all variables except vehicle price, N is the number of vehicle types (specification) with non-zero registrations. For prices, N report the number of matched vehicle types in both registration dataset and price dataset.

Table A2

Vehicle registration tax in Norway from 2005 to 2014

Vehicle Registration Taxes	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Piston displacement tax (NOK/cm3)										
Initial 1200 cm^3	10.26	10.44								
Next 600 cm^3	26.86	27.33								
Next 400cm^3	63.18	64.29								
Remainder	78.93	80.31								
Weight tax (NOK/kg)										
Initial 1150 kg	34.75	35.36	33.16	34.02	35.04	35.67	36.31	36.89	37.59	38.19
Next 250 kg	69.5	70.72	72.27	74.15	76.37	77.74	79.14	80.41	81.94	83.25
Next 100 kg	139	141.43	144.55	148.31	152.76	155.51	158.31	160.84	163.9	166.52
Remainder	161.66	164.49	168.11	172.48	177.65	180.85	184.11	187.06	190.61	193.66
Motor effect tax (NOK/kw)										
Initial 65 kw (70kw in 2014)	134.22	136.57	120.59	123.73	127.44	55.10	0	0	0	0
Next 25 kw (30kw in 2014)	489.54	498.11	502.47	515.53	531.00	481.00	466.00	315.00	275.00	235.00
Next 40 kw	979.38	996.52	1205.92	1237.27	1274.39	1297.33	1302.68	895.00	790.00	665.00
Remainder	1657.36	1686.36	2512.33	2577.65	2654.98	2702.77	2751.42	2220.00	1960.00	1650.00
CO_2 emission tax (NOK/ (g/km))										
Initial 120 g/km (115 g/km in 2011, 110g/km in 2012 and 2013, 105 g/km in 2014)	0	0	40.20	41.25	0	0	0	0	0	0
Next 20 g/km (15 g/km in 2013 and 2014)	0	0	190.94	195.90	526.00	725.00	738.00	750.00	764.00	776.00
Next 40 g/km	0	0	502.47	515.53	531.00	731.00	744.00	756.00	770.00	782.00
Next 70 g/km			1406.90	1443.48	1486.78	1704.00	1735.00	1763.00	1796.00	1915.00
Remainder	0	0	1406.90	1443.48	2500.00	2735.00	2784.00	2829.00	2883.00	3500.00
Allowance for below Initial 50 g/km	0	0	40.20	41.25	500.00	609.00	738.00	850.00	966.00	981.00
Allowance for emission from 50 g/km to 120 g/km (115 g/km in 2011, 110g/km in 2012 and 2013, 105 g/km in 2014)	0	0	40.20	41.25	500.00	609.00	620.00	750.00	814.00	827.00
NOx emissions (NOK/(mg/km))								22.00	35.00	46.00

Appendix B. New sales vehicles

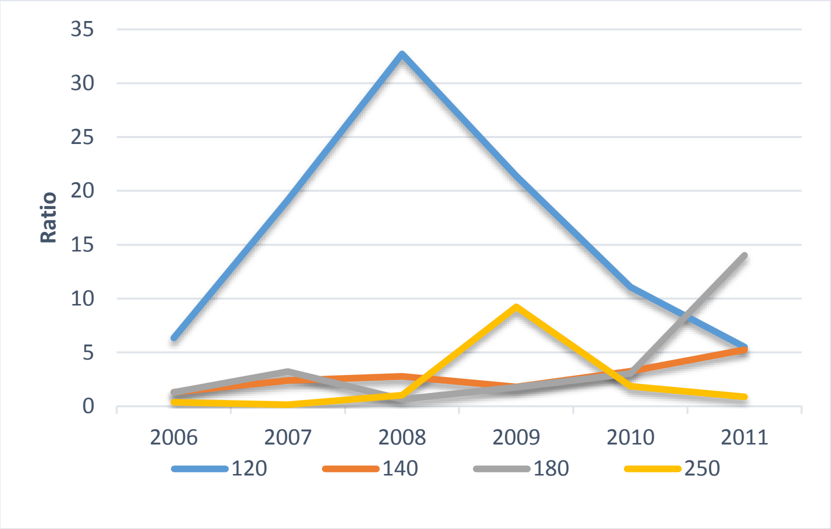


Fig. B1. Ratio of number of vehicles below the intensity cutoffs to the number above, Norway

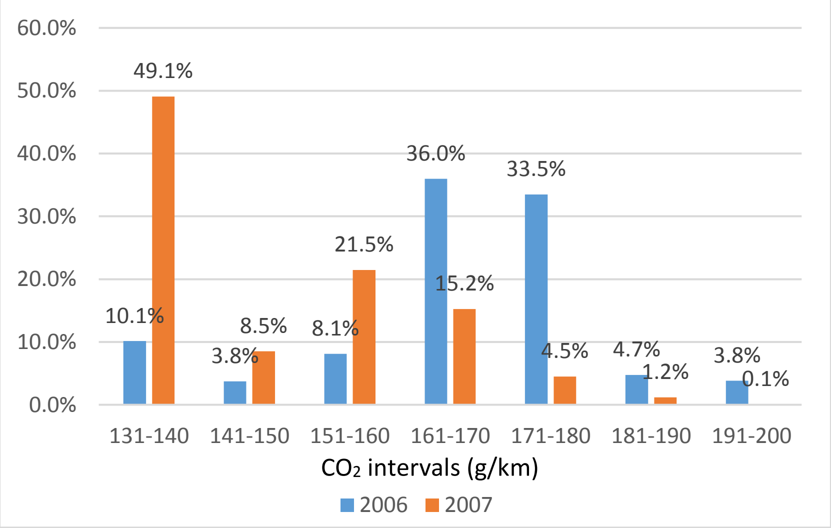


Fig. B2 Sales share of specifications within Volkswagen golf

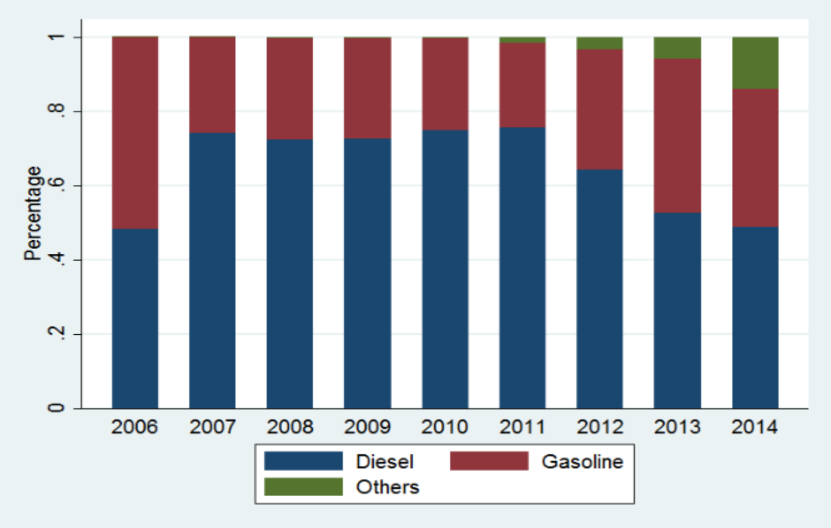


Fig. B3 Shares of diesel-powered vehicles and gasoline-powered vehicles from 2006 to 2014

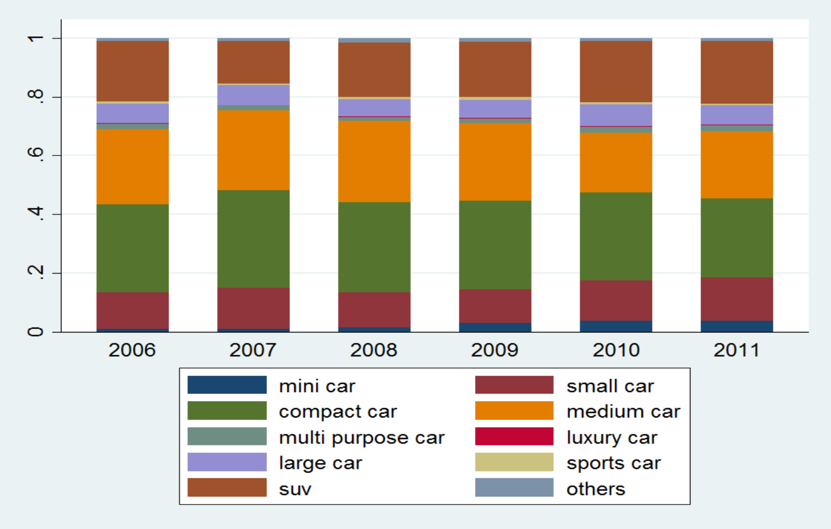
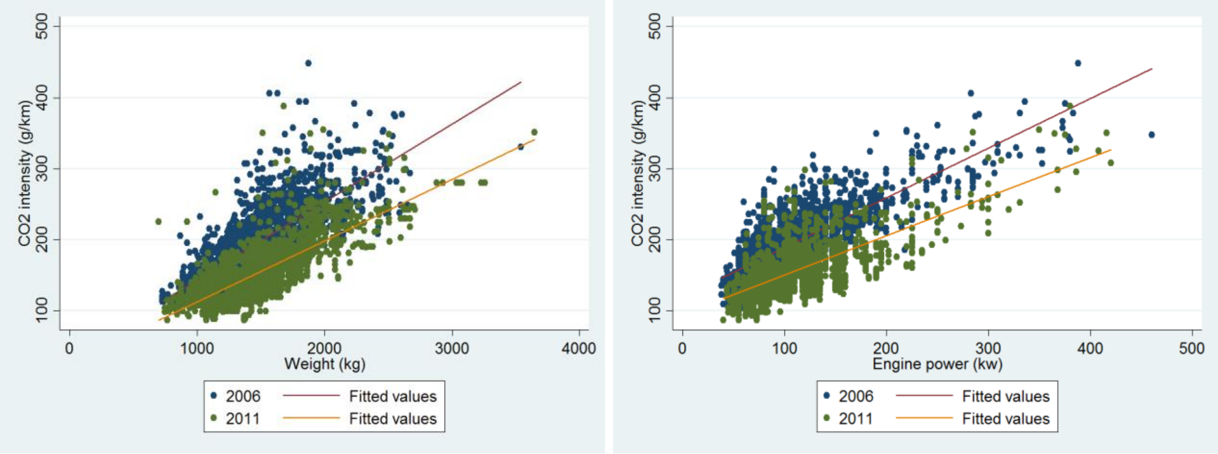


Fig. B4 New vehicle sales by segments



(a) (b)

Fig. B5. Trade-offs between vehicle characteristics, 2006 and 2011. Note: (1) is for CO_2 intensity and weight; (2) is for CO_2 intensity and engine power.