The Environmental Impact of Vehicle Circulation Tax Reform in Germany

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Abstract

A core political strategy for reducing greenhouse gas emissions from road transportation in Germany is to incentivize the purchase of motor vehicles with relatively low tailpipe CO_2 emissions. Consequently, since mid-2009, owners of new cars in Germany face an annual vehicle circulation tax that is partially levied according to vehicles' CO_2 emission index. In this paper, I estimate the effect of CO_2 -based vehicle circulation taxation in Germany on annual CO_2 combustion emissions from passenger cars and CO_2 climate costs using a nested logit approach on a novel panel-dataset containing registration, cost and vehicle characteristic information on approximately 7,000 unique vehicle models and approximately 19.5 million new vehicle registrations in Germany from 2007 to 2013. This approach first yields vehicle model specific estimates for the elasticity of new vehicle registrations with regard to the circulation tax. These elasticities are used to estimate changes in new vehicle registrations by model, which are then combined with model-specific CO_2 emission factors and segment-specific annual distances driven to yield total emission changes attributable to the change in vehicle circulation tax. Finally, physical changes in emissions are converted into changes in monetary climate damages. Uncertainty in the elasticity of new vehicle registrations by segment with regard to vehicle circulation tax, the fuel economy and corresponding CO_2 emission indices of vehicles, distances traveled by market segment, and in the monetary damages resulting from CO_2 emissions are propagated through the analysis. Overall I find statistically significant, but relatively small reductions in CO_2 emissions and climate costs due to the change in taxation: When simulating the ceteris paribus effect of the most stringent taxation regime implemented in 2014 on the pre-tax change models available in 2008, median registrations are estimated to decrease by approx. 9,500 vehicles, or 0.3 per cent of total new registrations. In addition, changes in registrations of individual vehicle models within each market segment lead to a relatively small reduction of segment-specific CO_2 emission indices (0.03 to 0.1 per cent across segments). The reduction in new registrations and reduction in CO_2 emission indices decrease median CO_2 combustion emissions from newly registered vehicles by 35,000 t (90 per cent confidence interval: 31.000 to 39.000 t), and climate costs by € 1.1 Million (90 per cent confidence interval: € 0.1 to 2.2 Million), or 0.4 per cent of total CO_2 emissions and climate costs from newly registered cars.

Key words: vehicle circulation tax, road transportation, climate costs, nested logit model

1. Introduction

In 2012, road transportation was responsible for 19.7 per cent of total greenhouse gas emissions (GHG) in the European Union (EU) and while most other sectors decreased emissions, road transportation emissions increased from 1990 to 2012 by 17 per cent (European Energy Agency, 2014a). Light duty-vehicles (cars and vans) accounted for the majority (~76 per cent) of road transportation GHG emissions in 2012 (European Commission, 2015). The European Union is aiming to reduce greenhouse gas emissions of the transportation sector by 60 per cent by the year 2050, compared to 1990 levels (European Commission, 2011). As an intermediate goal, emissions should be 20 per cent lower in 2030 than in 2008 (European Commission, 2011). Moreover, existing legislation in the European Union (EU) requires all member states to reduce total greenhouse gas emissions by 20 per cent on average by 2020 in comparison to 1990 (European Council 2007, European Commission, 2009, European Union, 2009).

As EU road transportation is a non-Emissions Trading Scheme (ETS) sector, additional measures are required outside the ETS to reduce emissions of this sector. In order to incentivize reductions of GHG emissions of light-duty vehicles, the European Commission published a strategy in 1995 (European Commission, 2007) resting on three pillars, that were subsequently augmented and (partially) introduced into European legislation: 1) voluntary commitments from vehicle manufacturers to reduce vehicle GHG emissions, 2) enhanced consumer information about vehicle emissions, and 3) promotion of fuel efficient cars through fiscal measures.

With regard to the *first* pillar, in 1998 and 1999, the European Car Manufacturers Association, the Japan Automobile Manufacturers Association and the Korean Automobile Manufacturers Association committed to a voluntary reduction of average CO_2 tailpipe emissions of newly sold vehicles to 140 g CO_2/km by 2008, respectively 2009 (European Commission, 2009a). These commitments were later recognized by the European Commission in three separate Commission Recommendations (European Commission, 2009b, European Commission 2000a and 2000b). After reviewing the level of progress being made through the voluntary agreements, in 2007 the Commission announced the introduction of a legislative framework for binding tailpipe emission performance standards that was agreed upon in 2009 (European Commission, 2009a). The new regulation requires each vehicle manufacturer to decrease its fleet-wide average tailpipe CO_2 emissions of new vehicles sold to 130 g CO_2/km by 2015, and to 95 g CO_2/km by 2020.

With regard to the *second* pillar, the European Parliament and European Commission agreed on regulation to ensure that information on the fuel economy and CO_2 emissions of new passenger cars are shared with consumers (European Union, 1999). To this end, car dealerships are required to attach or display a label on fuel economy and CO_2 emissions on or near each new passenger car they are displaying.

With regard to the *third* pillar, there is no harmonized European framework for promoting fuel-efficient cars through fiscal measures. In terms of motor vehicle taxes, in 2005 the European Commission presented a proposal for a directive (European Commission, 2005) that would have required all member states to restructure the tax base of these taxes to be fully or partially CO_2 based. This draft directive was never approved by the European Council. In 2012 the Commission reiterated it, aiming for a harmonization of vehicle motor taxes across the EU according to the vehicle-specific CO_2 emissions (European Commission, 2012), but no new legislative action has been taken to date.

However, while EU member states are not *required* to levy CO_2 emission-dependent motor vehicle taxes, they are *allowed* to do so, and as of the end of 2014, 20 of 28 EU countries are using such schemes, of which 19 directly through a CO_2 component in their vehicle tax system, and one country (Denmark) indirectly through vehicle taxes based on fuel consumption (ACEA, 2015). Provisions in member states also differ according to the type of vehicle tax for which CO_2-emissions are accounted for and the tax basis. As can be seen in Table 1, 7 countries have introduced CO_2 components both into circulation and registration taxes, 4 into circulation taxes only, and 7 into registration taxes only. Besides Luxemburg and the Netherlands, no other country taxes vehicle ownership or purchase only according to CO_2 emissions, but includes other factors into the tax base such as engine size, vehicle weight and fuel type.

Table 1: Overview of CO_2-based vehicle taxes in the European Union

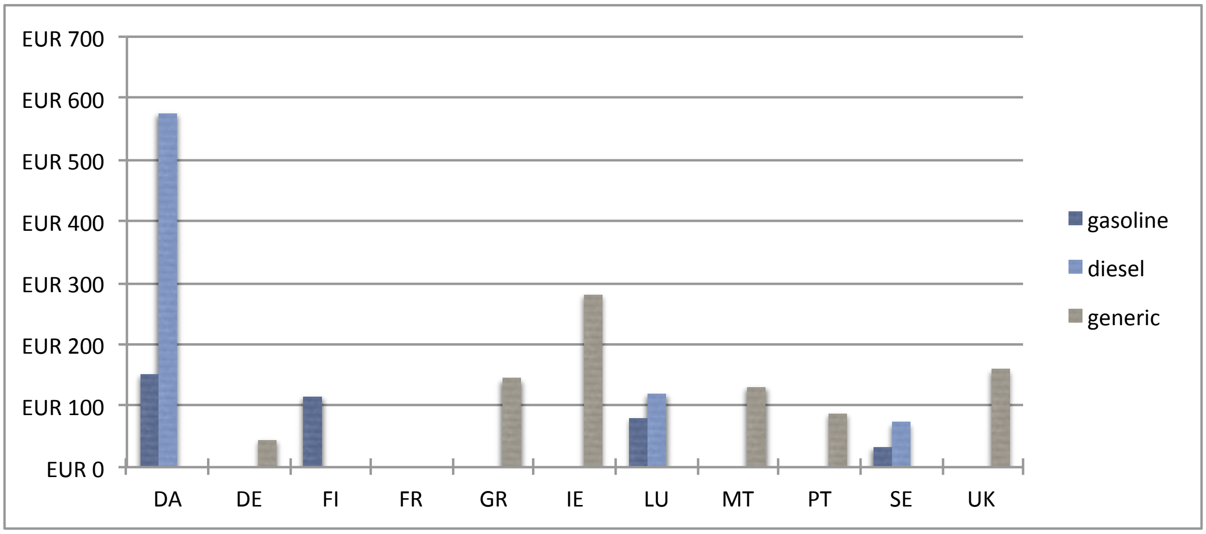
Type of tax	**Countries**
Circulation tax only	DE, EL, LU, SE,
Registration tax only	AT, HR, LT, RO, SI, ES, BE
Both	CY, DA, FI, FR, IE, MT, NL, PT, UK
Tax base	**Countries**
CO_2 only	LU, NL
CO_2 and other factors	AT, BE, CY, DA, DE, EL, ES, FI, FR, HR, IE, LT, MT, PT,RO, SE, SI, UK

Notes: Codes are official country codes.
Source: own depiction from ACEA (2015) data.

The amount payable for the CO_2 component varies significantly across the countries. Figures 1A and 1B show a notional example on vehicle taxes levied in European countries for an "average" vehicle newly registered in the EU in terms of 2012 fuel consumption, CO_2 emissions and sales price (5.3 l/100km; 132 g CO_2/km; € 25,561 inclusive of sales tax). The properties of the average car are taken from ICCT (2014) and the vehicle circulation and registration taxes are calculated using legal documents from the respective EU member states.

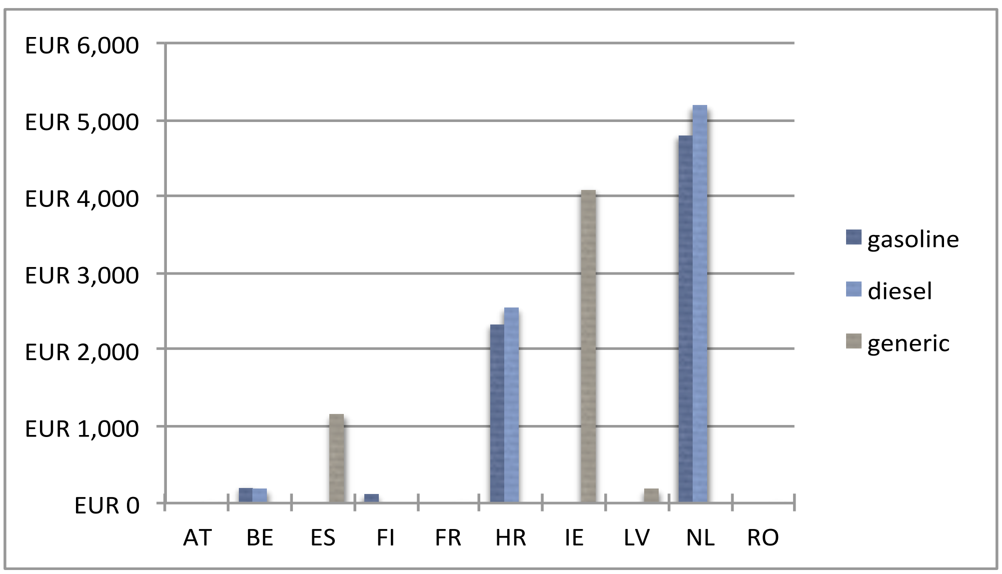
As can be seen from the figures 1A and 1B payments for both circulation tax and registration tax vary widely among EU countries for the average vehicle sold in the EU. The highest annual circulation tax for an average vehicle applies in Denmark (€ 363), while in France emissions of the average EU car are below a threshold level at which circulation taxes apply. Registration taxes for the average car vary from € 0 in Austria, France and Romania, to € 5187 in the Netherlands. Note that while no registration taxes apply for the average vehicle in three countries since CO_2 emissions are below the threshold level applicable in these countries, registration taxes apply for high polluting vehicles. For example, at emissions of 250 g CO_2/km, vehicle registration tax in France would cost € 8,000.

Fig. 1A: Comparison of annual vehicle circulation tax for selected countries



Notes: Assumes Euro 6 emission standard is fulfilled. "Generic" means no distinction between diesel and gasoline vehicle is being made in the respective country for tax calculation purposes.
Source: Own calculations using country-specific taxation sources.

Fig. 1B: Comparison of CO_2 component of registration tax for selected countries



Notes: Assumes Euro 6 emission standard is fulfilled. "Generic" means no distinction between diesel and gasoline vehicle is being made in the respective country for tax calculation purposes. Average vehicle price of € 25,561 (incl. taxes), net price for vehicle tax calculations determined using country-specific tax information.
Source: Own calculations using country-specific taxation sources.

In Germany, which is the biggest automobile market in the European Union (EEA 2013), policy-makers have committed to lowering greenhouse gas emissions by 40 per cent by 2020 compared to 2005 (Federal Ministry of Economics and Technology 2010). While no specific target exists for emissions' reduction from German road transportation, different policy measures have been implemented in order for road transportation to contribute to the overall emissions target, including a federal mandate for the use of biofuels and financial support for research and development of electric vehicles, energy storage devices and required infrastructure (Federal Ministry for the Environment, Nature Conservation, Building and

Nuclear Safety, 2014). A core component of the strategy for reducing emissions from road transportation is to incentivize the purchase of motor vehicles with relatively low GHG emissions (Deutscher Bundestag 2009a). In order to do so, since mid-2009, owners of new cars face an annual vehicle circulation tax that is partially levied according to tailpipe CO_2 emissions (Deutscher Bundestag 2009a).

The objective of the paper is to estimate the effect of the vehicle taxation reform in Germany on vehicle purchases and associated on-road emissions and climate damages of the vehicle fleet. It estimates aggregate consumer vehicle demand by vehicle segment using a nested logit model, as proposed by Berry (1994). By doing so it accounts for different strengths of substitution between different vehicle models. This approach yields vehicle model specific estimates for the elasticity of new vehicle registrations with regard to the circulation tax. These elasticities are used to estimate changes in new vehicle registrations within and between segments, which are then combined with model-specific CO_2 emission factors and annual distances driven to yield total emission changes attributable to the change in vehicle circulation tax. Finally, physical changes in emissions are converted into changes in monetary climate damages using CO_2 damage cost estimates.

My work adds to only a small number of studies of the impact of carbon-based vehicle taxation. Most work in the area has analyzed the US case (Greene et al., 2005; Fischer, 2008; Bastard, L., 2010), and only a limited number of studies have dealt with countries in the European Union (D'Hautfœuille et al., 2014, Huse and Lucinda, 2014; Adamou et al.; 2012; Bastard, 2010). For Germany, there has been some work on CO_2 based taxation using data predating the actual reform in 2009 (Adamou et al., 2012 and 2014, Zachariadis, 2013; Vance and Mehlin, 2009). In a discussion paper, Klier and Linn (2012) apply a reduced-form relationship between taxes and new vehicle registrations instead of a consumer demand function on a dataset comprising two years before the reform and the immediate aftermath of the reform (second half of 2009). They find a significant short-term impact of the vehicle circulation tax on the demand for vehicle models.

Against this background, the contribution of the paper is twofold: Firstly, it adds to the sparse literature on the evaluation of CO_2 based vehicle taxation by estimating the impact of the tax reform in Germany - Europe's biggest car market - on motor vehicle purchases and associated on-road CO_2 emissions. By doing so, it secondly provides insight into the effectiveness of environmental policies for mitigating GHG emissions from road transportation using a measure which influences GHG emissions indirectly at the vehicle purchase step as opposed to measures that directly influence on-road emissions such as fuel taxes or biofuel mandates.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of the design of the circulation tax in Germany before and after the tax reform and describes the development of vehicle registrations by market segments over time. Section 3 outlines the economic rationale for a CO_2-based vehicle circulation tax, followed by the development of the estimation strategy in section 4. Section 5 describes the data used and section 6 discusses and interprets the results. The final section concludes.

2. Design of the annual circulation tax in Germany and development of German automobile market by segment

Before the vehicle tax reform in July 2009, the annual motor vehicle tax was levied according to the vehicle's engine type, diesel or gasoline, it's engine displacement measured in cubic centimeters (cc) and the European emission standard (Euro 1/2/3 or better) (Bundesministerium der Justiz, 2016). For vehicles newly registered after July 2009, the annual motor vehicle tax is levied according to the type of engine (diesel or gasoline), the engine displacement (cc) and according to the listed average vehicle's CO_2 emission index. The CO_2 component of the tax increases linearly with CO_2 emissions of a vehicle. The amount effectively payable for the CO_2 emissions depends on a base value that becomes more stringent over time (120 g CO_2/km in 2009 to 95 g CO_2/km in 2014). The vehicle owner is obliged to pay € 2 for each g CO_2/km for which the vehicle's listed CO_2 emission index exceeds the base value. Table 2 provides an overview of the different tax rates before and after the reform.

Table 2: Pre-reform and post-reform composition of annual circulation tax in Germany

	Registered before July 2009			Registered after July 2009	
Component	**EU Norm**	**Diesel**	**Gasoline**	**Diesel**	**Gasoline**
Engine displacement (Euros per 100 cc or part thereof) depending on EU norm	**EU norm**			€ 9.50	€ 2.00
	< Euro 1	€ 33.27 - 37.85	€ 21.07 - 25.36		
	Euro 1	€ 27.35	€ 15.13		
	Euro 2	€ 16.05	€ 7.36		
	Euro 3 or better	€ 15.44	€ 6.75		
CO_2 Emissions (Euros per g/km CO_2 emission over the base value*)	n/a	n/a	n/a	€ 2.00	

Notes: *120 g/km for vehicles registered before 01/01/ 2012, 110 g/km for vehicles registered between 01/01/2012 and 31/12/2013 and 95 g/km for vehicles registered from 01/01/2014.

The vehicle market can be divided into different segments. The segmentation used in this paper follows the classification used by the German Federal Motor Transport Authority (Kraftfahrtbundesamt (KBA)), in which vehicle models are allocated to a certain segment based on, inter alia, optical characteristics such as size, and selling prices (KBA, 2011). I use six passenger car market segments: Mini, Small, Lower Midrange, Midrange, Upper Midrange, Large and Luxury. The last segment is the sum of smaller KBA market segments (Upper class, Van, Sports car, Off-road vehicle, SUV). Table 3 provides an overview of the market segments and main characteristics for each segment for the year 2013.[1]

The average CO_2 emission index of all newly registered vehicles in Germany in 2013 was 134.5 g CO_2/km, compared to a EU average of 127 g CO_2/km (ICCT, 2014). In 2013, the relevant base value for the taxation of vehicles' CO_2 emissions was 110 g CO_2/km for newly registered vehicles. According

[1] The analysis from here on excludes vehicles with alternative engine types, whose market share in the German automobile market is very small (total in 2013 = 1.58 per cent, thereof electric cars (2013 = 0.20 per cent), hybrids (2013 = 0.89 per cent), natural gas/wankel engines (2013 = 0.48 per cent); own estimation.

to Table 2 only the vehicles of the segment "Mini" are, on average, below the target value thus do not need to pay CO_2 based circulation tax.

Table 3: Segments of the car market and selected criteria in 2013

Segment	Best-selling vehicle (BSV) in segment	Market share (%) of BSV in segment	Market share (%) of segment in market	CO_2-emissions (segment avg.) g/km	KBA-segments included
Mini	VW Up	20.96	6.93	109.34 (106.99)[a]	Minis
Small	VW Polo	14.16	16.35	121.63 (120.53)[a]	Small
Lower Midrange	VW Golf/Jetta	32.37	25.56	124.62 (123.84)[a]	Compact class
Midrange	VW Passat	19.33	12.63	135.82 (135.61)[a]	Middle class
Upper Midrange	BMW 5 Series	33.20	4.54	147.09 (146.75)[a]	Upper middle class
Large and Luxury	VW Tiguan	26.52	28.83	153.74 (153.52)[a]	Upper class, Van, Sports car, Off-road vehicle, SUVs[b]

Notes: [a] average value including alternative fuels, [b] from 2013 onward specified as a separate category.
Source: own depiction using KBA data

Table 4: Costs of circulation tax by vehicle before and after the tax reform; Diesel vehicle

Segment; BSV of 2013	Weighted avg. CO_2-emissions BSV (2013; g/km)	Weighted avg. engine displacement BSV (2013; cc)	Notional circulation tax in January 2009 BSV (€)	Notional circulation tax in 2013 BSV (€)	Difference (€)
Mini; Fiat 500[a]	112.72 (104.51)*	1,449 (999)*	15.44 x 15 = 231.60	9.50 x 15 + 2 x 2.72 = 147.93	-83.67
Small; VW Polo	102.40 (121.64)*	1,464 (1,270)*	15.44 x 15 = 231.60	9.50 x 15 = 142.50	-89.10
Lower Midrange; VW Golf/Jetta	110.73 (120.53)*	1,745 (1,508)*	15,44 x 18 = 277.92	9.50 x 18 + 2 x 0.73 = 172.46	-105.46
Midrange; VW Passat	128.82 (131.25)*	1,937 (1,913)*	15,44 x 20 = 308.80	9.50 x 20 + 2 x 18.82 = 227.63	-81.17
Upper Midrange; BMW 5 series	140.42 (142.52)*	2,401 (2,423)*	15,44 x 25 = 386.00	9.50 x 25 + 2 x 30.42 = 298.35	-87.65
Large and Luxury; VW Tiguan	152.96 (156.83)*	1970 (1,847)*	15.44 x 20 = 308.80	9.50 x 20 + 2 x 42.96 = 275.91	-32.89

Notes: * overall average of diesel and gasoline; **all in 2013 newly registered vehicles are Euro 5 norm or better. [a] The VW up! Is not produced with diesel engines, therefore data here is given for the second most popular vehicle, the Fiat 500, with a segment share of 14.19 per cent (VW up!: 21 per cent) and a market share of 0.98 per cent (VW up!: 1.45 per cent).

Table 4 and Table 5 compare the costs of a notional circulation tax before and after the tax change for the best-selling vehicle of each segment in the year 2013 for diesel vehicles (Table 4) and gasoline vehicles (Table 5).

Table 5: Costs of vehicle circulation tax before and after the tax reform; Gasoline vehicle

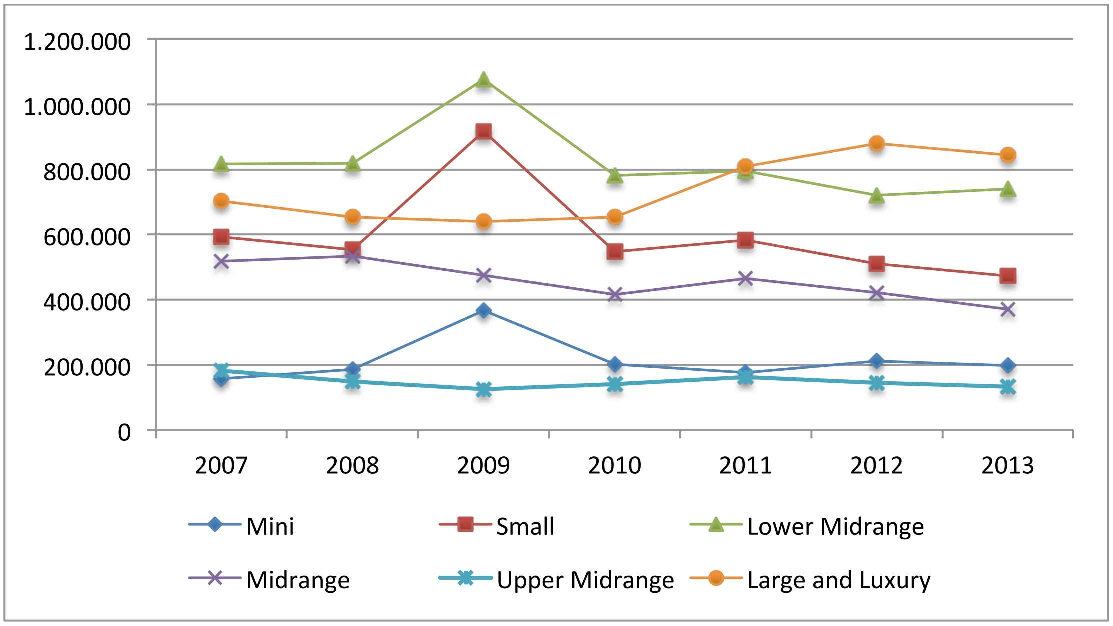
Segment; BSV of 2013	Weighted avg. CO_2-emissions BSV (2013; g/km)	Weighted avg. engine displacement BSV (2013; cc)	Notional circulation tax in January 2009 BSV (€)	Notional circulation tax in 2013 BSV (€)	Difference (€)
Mini; VW Up	104.51 (104.51)*	999 (999)*	6.75** x 10 = 67.50	2 x 10 = 20	-47.5
Small; VW Polo	125.52 (121.64)*	1231 (1270)*	6.75 x 13 = 87.75	2 x 13 + 2 x 15.52 = 57.04	-30.71
Lower Midrange; VW Golf/Jetta	127.64 (120.53)*	1334 (1508)*	6.75 x 14 = 94.50	2 x 14 + 2 x 17.64 = 63.29	-31.21
Midrange; VW Passat	154.62 (131.25)*	1684 (1913)*	6.75 x 17 = 114.75	2 x 17 + 2 x 44.62 = 123.25	+8,50
Upper Midrange; BMW 5 series	170.04 (142.52)*	2703 (2423)*	6.75 x 28 = 189	2 x 28 + 2 x 60.04 = 176.07	-12.93
Large and Luxury; VW Tiguan	166.80 (156.83)*	1530 (1847)*	6.75 x 16 = 108	2 x 16 + 2 x 56.80 = 145.60	+37.60

Notes: * overall average of diesel and gasoline; **all 2013 vehicles are Euro 5 norm or better.

As Tables 4 and 5 show, all best-selling diesel vehicles in each vehicle segment and most of the best-selling gasoline vehicles pay less circulation tax under the reformed tax system in 2013.

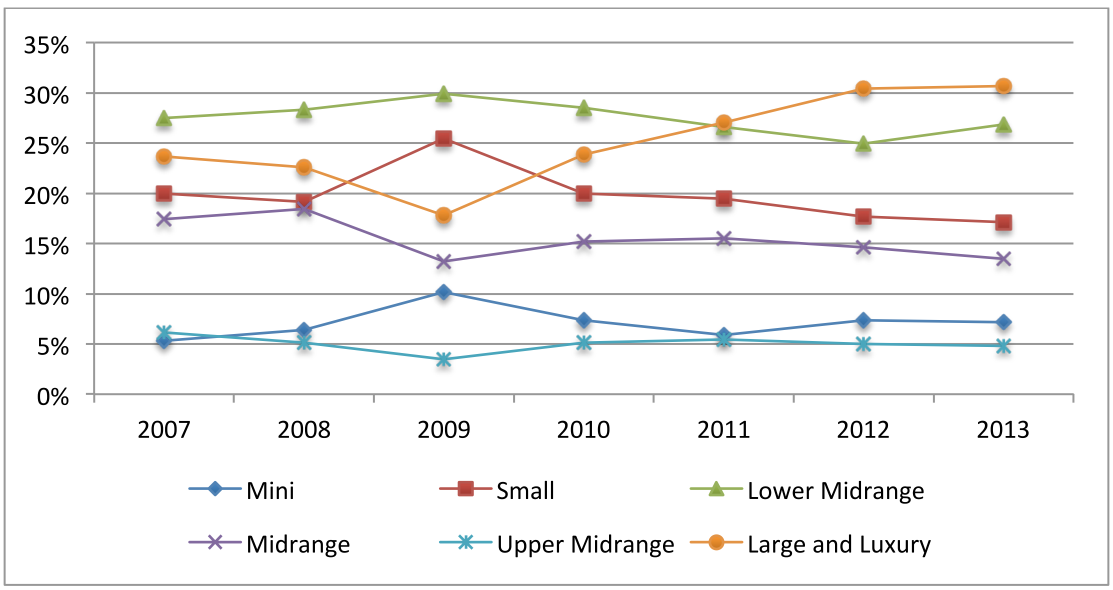
The first three segments (mini, small, and lower midrange) have an overall market share of almost 50 per cent of the newly registered vehicles and do not differ significantly in the amount of the notional tax under the reformed tax. An exception might be diesel vehicles in the mini segment, which are significantly cheaper than vehicles from other segments. Figure 2 shows a time series of newly registered cars in Germany, divided into segments, from 2007 to 2013 and Figure 3 shows the share of the segments at total new registrations during the same time.

Fig. 2: Registrations of new vehicles divided into segments (2007-2013)



Source: own depiction using KBA data.

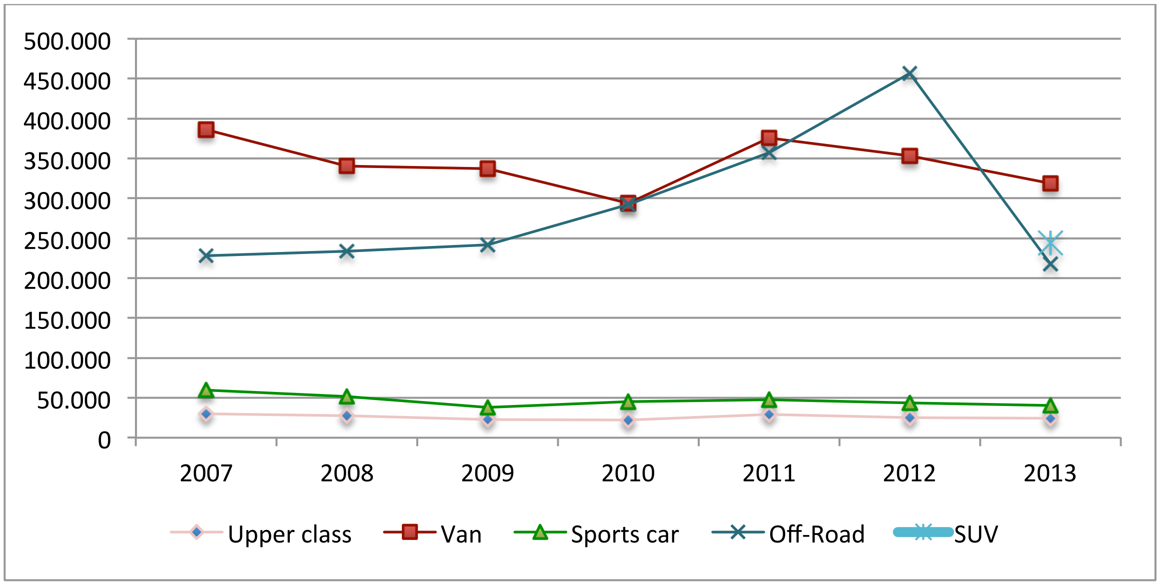
Fig. 3: Share of new registrations in vehicle segments at total new vehicle registrations (2007-2013)



Source: own depiction using KBA data.

With the exception of the "large and luxury segment", total registrations by segment have remained flat or decreased from 2007 to 2013. The "large and luxury" segment has increased by 72 per cent, or a total of 12.9 percentage points, from its low in 2009, to a market share of 30.7 per cent of newly registered vehicles in 2013. As Figure 4 shows, this increase can be explained by a rising popularity of SUVs (which were listed under off-road vehicles until 2013), which in 2013 accounted for approximately 30 per cent of all new registrations in the Large and Luxury segment at average CO_2 emissions of 150.2 g CO_2/km.

Fig. 4: New registrations in segment "Large and Luxury" (2007-2013)



Notes: SUVs were classified as Off-Road until 2013 and are listed separately thereafter.
Source: own depiction using KBA data.

Figures 2 and 3 also depict a one-off spike in new registrations in 2009 in the three lower segments, which coincides with the change in vehicle circulation tax formula. However, 2009 was also the year in which a car scrapping scheme was introduced to stabilize the new vehicle market in the aftermath of the world financial crises which depressed consumer spending. Through the scheme new car purchases were subsidized with € 2,500 if the owner's previous vehicle was scrapped (Deutscher Bundestag, 2009b). In total, approximately 1.9 million vehicles were registered under the scheme, accounting for about 50 per cent of all new registrations in 2009. Against this background, a visual observation of changes in registrations around the time of vehicle circulation tax change remains inconclusive in terms of causality.

3. Economic Rationale for a CO_2-based vehicle circulation tax

Contrary to measures that influence total tailpipe emissions by changing fuel types such as biofuel mandates, or by changing fuel consumption such as fuel taxation, circulation taxes can influence on-road emissions from passenger cars only indirectly.

Total CO_2 emissions from passenger cars in a year t (TCO_{2_t}) can be expressed by the following equation:

$$(1)\ TCO_{2_t} = V_t \times EI_t \times VD_t$$

with TCO_{2_t} as the sum of the CO_2 emissions from the car fleet in Germany, V_t as the number of vehicles in Germany in the fleet, EI_t as average emission index of the fleet (in units of CO_2 emissions per distance unit) and D_t as annual vehicle distance driven by a vehicle, all in year t.

Ceteris paribus, CO_2 emissions decrease if the number of vehicles decreases, the average GHG intensity per distance unit driven decreases or the annual average distance by car decreases.

The change in vehicle circulation tax is supposed to decrease the average emission index of passenger cars in Germany. This emission index can be expressed as:

$$(2)\ EI_t = \frac{\sum_{j=1}^{n}(v_{j,t} \times EI_{j,t})}{V_t}$$

with $v_{j,t}$ as the number of vehicles of model *j* in the fleet and $EI_{j,t}$ as the emission index of vehicle model *j* (in units of CO_2 emissions per distance unit), all in year t.

The circulation tax reform aims at changing the composition of the vehicle fleet V_t to a higher share of relatively low-emitting vehicles, thereby decreasing the fleet-wide emission index *EI*. The circulation tax can impact purchasing decisions for new vehicles, thereby changing the number and split of new vehicle registrations as shown in equation 3:

$$(3)\ V_t = \sum_{j=1}^{n} v_{j,t} = \sum_{j=1}^{n} VS_{j,t-1} + \sum_{j=1}^{n} VN_{j,t} - \sum_{j=1}^{n} VR_{j,t}$$

with $v_{j,t-1}$ as the vehicle stock of model *j* of the previous year *t-1*, $VN_{j,t}$ as the newly registered vehicles of model *j* in year *t*, $VR_{j,t}$ as the number of retirements of model *j* in year *t*.

Changes in new registrations are driven by the purchasing decisions of consumers:

$$(4)\ VN_{j,t} = f(\sum_{j=1}^{m} D_{i(j),t})$$

$D_{i(j)}$ is the simplified individual demand by consumer *i* for model *j*:

$$(5)\ D_{i(j)} = f(p_j, ct_j, x_j, s_j, \zeta_j)$$

with p_j as the price for car j, ct_j as the annual vehicle circulation tax, x_j as car j's vehicle characteristics, s_i as the individuals socioeconomic factors and ζ_i as the individuals preferences.

The economic idea behind the circulation tax is to relatively increase the costs of vehicles with relatively high CO_2 emissions, therefore making them more expensive in relation to low emitting vehicles and thus to induce a demand shift toward lower emitting vehicles. Consequently, the impact of the CO_2-based annual circulation tax on the consumer demand for cars depends on two factors: on the weight that an individual puts on the annual circulation tax component in his vehicle demand in particular, and on the discount rate that the individual applies at the time of purchase for the recurrent tax payments for subsequent years. The weight might be determined by factors like individual preferences, income or awareness / education. The discount rate determines, how much an individual considers future payments of the circulation tax. Economic theory suggests, that the actual individual discount rate can be high, which is known as the "defective telescopic faculty" and implies that, ceteris paribus, future payments might not be noticed as much as present payments and thus impact purchasing decisions less (Hausman, 1979; Warner and Pleeter, 2001). Overall, the political success of the CO_2-based tax in terms of a demand shift toward lower CO_2 emitting vehicles relies on how much attention the individual pays to the tax in its decision to buy a car. The hypothesis is, that the higher the actual tax and the more detectable the tax, the more it will affect the decision about which car to buy and contrary, the lower the tax and the less detectable, the less influence it will have on the same decision. This hypothesis is in accordance with findings about tax salience (e.g. Busse et al., 2006; Chetty et al., 2009; Finkelstein, 2009). However, the actual extent to which the CO_2-based taxation factors into vehicle purchasing decisions needs to be explored data-based, which is pursued in the following sections.

4. Estimation strategy

Estimation of the impact of the vehicle tax reform on consumers' vehicle demand is derived from individual car choice, which is modeled with the help of an individual indirect utility function. As proposed for different research questions by McFadden (1981) and Berry (1994), I do not intend to estimate individual demand, but rather to estimate a market level demand system, which is derived through an individual choice model. This approach is used, since there is no representative individual-level data on car choice. The aggregated model needs to approximate consumer choice behavior through available aggregated data and needs to make assumptions about demand substitution patterns, which are driven by the functional form of the assumed utility function.

One can distinguish between three main model types that could possibly be applied here. First, the logit demand model (McFadden, 1974) implies that the choice between different car models depends on the market share of each vehicle alone, independent of any interaction between consumer and vehicle characteristics. Second, the nested logit (NL) model based on McFadden (1978) and Berry (1994) allows for more flexible substitution patterns, as consumer preferences can be correlated across products within a priori defined segments ("nests"). This indicates that consumers have higher substitution preferences between vehicles of the same segment than between vehicles from any other predefined group. Third, the random coefficients (RC) model for aggregated demand (Berry et al., 1995) is an unrestricted form of the NL model and allows consumer preferences and vehicle characteristics to be correlated across all options, without the boundaries of predefined groups. Substitution will take place according to similarity of vehicles' characteristics and not because they were defined as being a close substitute. This flexibility, however, comes at the cost of computational complexity, as, unlike the logit and nested logit models, the RC model has to be solved numerically. The complexity might lead to a reduction in the models performance, as has been studied by Knittel and Metaxoglu (2014), Dubé et al. (2012) and Judd and Skrainka (2011). In addition, Grigolon and Verboven (2014) conducted a Monte Carlo Simulation to compare the performance of these three model types. Their results show that NL and RC models bring about the same elasticities and equally robust results, while the logit model results are less robust.

Given the results from the literature, I will apply a nested logit model to estimate aggregate consumer vehicle demand, as proposed by Berry (1994), who draws on prior work from Ben-Akiva (1974), McFadden (1978), Bresnahan (1981 and 1987), Cardell (1991) and Feenstra and Levinson (1995). In this model the individual utility that consumer i derives from vehicle j in market m, $U(p_{jm}, x_{jm}, \xi_{jm}, \nu_i; \theta)$, is a function of the vehicle price p_{jm}, observed and unobserved vehicle characteristics x_{jm} and ξ_{jm}, as well as unobserved individual characteristics ν_i, and unknown demand parameters to be estimated, θ. Observed and unobserved car and consumer characteristics are considered to avoid endogeneity resulting from omitted variable bias.

An often-used general indirect utility specification for vehicle demand is:

$$(6)\ u_{ijm} = x_{jm}\beta_i - \alpha_i p_{jt} + \xi_{jm} + \bar{\epsilon}_{i,j,m}$$

where α_i is the price coefficient, which reveals the impact of the price of vehicle j on utility for consumer i, where β_i is a k-dimensional vector of random taste coefficients for alternative j and where $\bar{\epsilon}_{i,j,m}$ reflects an additional individual-specific valuation for alternative j, which is randomly distributed within the population.

In order to specify this general approach, the following assumptions and parameter requirements are appointed. x_{jm} is a k-dimensional vector of vehicle characteristics that varies with the vehicles j but is equal to all consumers i. Furthermore, I assume that $\beta_i = \beta$, so that the taste coefficients in β can be interpreted as mean coefficients for the respective vehicle characteristics within the studied population.

Since transaction data of car sales is not available, the vehicle list price p_{jm} is used in this estimation. Thus, I implicitly assume that vehicle prices are (ceteris paribus) identical for all consumers. De facto car dealerships often offer discounts and using the list price might induce bias. This, along with the correlation between p_{jm} and ξ_{jm} $(E(p_{jm} \mid \xi_{jm}) \neq 0)$, motivates estimation procedures, which avoid the resulting bias such as the instrument variable approach. Price enters utility with the coefficient α_i, the marginal utility from income of consumer i. To allow for (restricted) interaction of income and price and in order to model wealth effects with regard to car demand, α_i is initially specified as $\alpha_i = \frac{\alpha}{\bar{Y}_m}$. The expression is an approximation for the Cobb-Douglass utility specification of Berry et al. (1995)[2] and follows Grigolon and Verboven (2014).

As a distinctive setting in Germany, however, a car scrappage scheme was in place in 2009. Buyers of new cars, under certain conditions, received a premium of 2,500 Euro when they scrapped their old car (BAFA, 2009). In order to account for this effect, the subsidy is assumed to reduce the sales price of the car, which yields

$$(7)\quad \frac{\alpha_0 p_{j,m}}{\bar{Y}_m} - \frac{\alpha_1 esp_{j,m}}{\bar{Y}_m}$$

where $esp_{j,m}$ captures the expected scrappage premium for vehicle j in market m, with $\alpha_0 \leq 0$ and $\alpha_1 \geq 0$, where α_0 captures the marginal utility from income of consumer i and α_1 captures the additional marginal utility from the expected scrappage premium. Through not a priori assuming $\alpha_0 = \alpha_1$, I account for car dealers who might reduce discounts to buyers so that there is no 100 per cent pass-through of the scrappage premium (Busse et al. (2006); Kaul et al. (forthcoming)). The expected scrappage premium for each vehicle j results from the paid scrappage premium sp at 2500 Euros, weighted by the probability of the buyer claiming the premium $w_{j,m}$. $sp_{j,m}$ is thus defined as $esp_{j,m}$=$w_{j,m} * sp$, where $w_{j,m} = \sum_{m=1}^{M}[Prem_{j,m}/J_{j,m}]$ with $Prem_{j,m}$ reflecting the share of vehicles j, which are chosen in combination with the scrappage premium, and $J_{j,m}$ reflecting the number of all consumer chosen vehicles j, in m.

The term x_{jm} includes only observed vehicle characteristics, therefore I explicitly add unobserved vehicle characteristics ξ_{jm} in the indirect utility function to avoid bias due to omitted variables. ξ_{jm} varies for vehicles but is constant for all consumers, which assumes that the unobserved vehicle characteristics of vehicle j in market m provoke the same average utility for every consumer *i*. In this case, the coefficient of the vehicle price captures variations in the utility through unobserved vehicle characteristics (thus: $E(p_{jm} \mid \xi_{jm}) \neq 0$). In an effort to decompose the drivers of these unobserved characteristics, I assume $\xi_{jm} = \xi_b + \xi_m + \Delta\xi_{jt}$. ξ_b is a dummy for unobserved vehicle's brand fixed effects, which are the same for all vehicles j belonging to the same brand b and are time-invariant for vehicle j of brand b. ξ_m is a dummy which controls for any market-specific unobservable fixed effects that can lead to demand shocks. $\Delta\xi_{jm}$ captures residual unobserved vehicle characteristics. Even though ξ_m would take up parts of the effect of the car scrappage scheme of 2009, leaving out the explicit modeling might lead to omitted variable bias, which is why equation (7) was introduced.

In the NL model the $\bar{\epsilon}_{ijm}$ are allowed to be correlated across products. $\bar{\epsilon}_{ijm}$ comprises an i.i.d shock ϵ_{ijm} and ζ_{igm}, which is specific to a car segment g and supposed to approximate consumer tastes for this segment, with the distinction of segments following the above mentioned market segments 1 trough 6. Thus it varies over consumers but is constant for all vehicles in group g for a consumer i. Let $g_0, g_1, \dots g_G$ define $G + 1$ exhaustive and mutually exclusive car segments in Germany with $g = 0$ be-

2 For a more extensive derivation of this specification of a utility function see Berry et al. (1995).

ing the 'outside good', which reflects the option of not choosing any vehicle but other commodities.[3] I assume $\bar{\epsilon}_{ijm} = \zeta_{igm} + (1-\rho)\epsilon_{ijm}$, where ϵ_{ijm} is i.i.d. extreme value distributed and so is $\bar{\epsilon}_{ijm}$ through the random coefficient ζ_{igm} as shown by Cardell (1991). ζ_{igm} has a distribution function that depends on ρ. ρ is the nesting parameter and approximates for the preference of the substitution between vehicles within a nest (intra-group correlation in preferences). $0 \leq \rho < 1$ is assumed. The bigger ρ, the higher the substitutability of products. Therefore, interaction between products and heterogenous tastes of consumers is modelled within groups, allowing a correlation between tastes for alternatives within a group via the distribution of $\bar{\epsilon}_{ijm}$.

The utility function can now be specified as:

$$(8)\ u_{ijm} = x_{jm}\beta - (\alpha_0 p_{j,m} - \alpha_1 esp_{j,m})/\bar{y}_m + \xi_{jm} + \zeta_{ig} + (1-\rho)\epsilon_{ijm}$$

According to Berry (1994) and Cardell (1997), (2) can be interpreted as a model, which carries the random coefficient ζ_{igm} only on group specific dummies d_{jgm}. d_{jgm} equals one whenever $j \in g$ and zero otherwise. The indirect utility from above can then be rewritten as:

$$(9)\ u_{ijm} = \delta_{jm} + \sum_g \left(d_{jgm}\zeta_{igm}\right) + (1-\rho)\,\epsilon_{ijm}$$

with $\delta_{jm} = x_{jm}\beta - (\alpha_0 p_{j,m} - \alpha_1 esp_{j,m})/\bar{y}_m + \xi_{jm}$ as the mean utility for product j.

To further structure the drivers of utility u_{ijm}, I decompose u_{ijm} into a mean valuation of each vehicle type j, δ_{jm}, and an individual specific deviation from this mean, ν_{jm}, which represents the additional heterogenous valuation of vehicle type j. This yields:

$$(10)\ u_{ijm} = \delta_{jm} + \nu_{jm},$$

where $\delta_{jm} = x_{jm}\beta - (\alpha_0 p_{j,m} - \alpha_1 esp_{j,m})/\bar{y}_m + \xi_{jm}$ and $\nu_{jm} = \sum_g \left(d_{jgm}\zeta_{igm}\right) + (1-\rho)\,\epsilon_{ijm}$. This shows that, within a group g, the heterogenous valuation of consumer i for all options of this group has a fixed component ζ_{igm}, which does not vary over alternatives, and the consumer specific term $(1-\rho)\epsilon_{ijm}$.

From the aggregated market perspective, the observed market share S_j of vehicle j results from the share of consumers who choose vehicle j relative to all consumers in the market, $S_j = C_{j,m}/\sum_{j=1}^{J} C_{j,m}$. With the utility of the outside good normalized to zero (Berry et al., 1995; Nevo, 2000) and assuming utility maximization as well as assuming consumer i will choose only one vehicle, a consumer i chooses good j if $u_{ijm} \geq u_{ikm}\ \forall\ k = 0,1,\ldots,$ J . Thus, the predicted market share $\hat{S}_t(\delta_t, \theta)$ can be derived from the summed probabilities of consumers choosing vehicle j, divided by the sum of the probabilities of all op-

[3] The aggregation of all other goods into one can be problematic and evaluation differences between vehicles and outside good might not be reflected accurately (see Train and Winston, 2007). However, it is necessary to include an outside option to estimate total market-level car demand. Otherwise an overall price increase in the vehicle market and none in other sectors would not trigger any substitution effects, like buying a used car instead, for example.

tions in the market. The individual evaluation of an option is determined by the mean valuation δ and the individual deviation from the mean ν, which is driven by $(1-\rho)\epsilon_{ijm}$ within a given group g, since optimization depends only on the differences in utility. Considering the Extreme Value distribution of ϵ_{ijm}, the utility maximizing choice probability can be expressed as:

$$(11)\quad \hat{S}_j(\delta,\rho) = \frac{e^{\delta_{jm}/(1-\rho)}}{D_g^{\rho}\left[\sum_g D_g^{(1-\rho)}\right]}$$

with $D_g \equiv \sum_{j\in g} e^{\delta_{jm}/(1-\rho)}$, which is the sum of the probabilities of all the choices in group g. To estimate this model it is assumed that $\hat{S}_j(\delta,\rho) = S_j$ in every market.

With the utility of the outside good normalized to zero ($\delta_0 = 0$) there is an analytical solution for δ_m, which is $\delta_m = \ln(S_{j,m}/S_{0,m}) - \rho\ln(S_{j/gm})$ and describes the composition of delta described by the logs of a division of observed market shares of all vehicles in market m ($S_{j,m}$), and the outside good ($S_{0,m}$) subtracted by the log of the observed within group market share ($S_{j/gm}$), weighted by ρ (Berry, 1994). This yields:

$$(12)\quad \ln(S_{j,m}) - \ln(S_{0,m}) = x_{j,m}\beta - \frac{\alpha_0 p_{j,m} - \alpha_1 esp_{j,m}}{\bar{Y}_m} + \rho\ln\left(S_{\frac{j}{gm}}\right) + \xi_{jm} = MS_{j,m}$$

with ($S_{j/gm}$) being the observed within-group share and $\xi_{jm} = \xi_b + \xi_m + \Delta\xi_{jm}$ and $MS_{j,m}$ representing the market share (MS) of vehicle j in market m. The individual demand has been transformed into market demand, which has become a linear function of ξ_{jm}. Therefore, the demand parameters $\theta = (\beta,\alpha,\rho)$ can now be estimated with the help of linear regression models.

Regression without regards to endogeneity, caused by a simultaneity problem due to the correlation between p_{jm} and $\Delta\xi_{jt}$ as well as the term ($S_{j/gm}$), which is endogenous by construction, would bring about potential estimation bias. To account for this bias, equation (7) is estimated via two-stage least squares instrumental variable estimation. Therefore, a vector of relevant and exogenous instrumental variables z_{jm} is needed to be interacted with the unobserved error term $\Delta\xi_{jm}$, for which $E[\Delta\xi_{jm} \mid z_{jm}] = 0$, so that $\Delta\xi_{jm}$ is mean independent of the vector of instruments z_{jm}. This assumption is milder than the often assumed $E[\xi_{jm} \mid z_{jm}] = 0$. Instruments are needed for the price and the within-group market share. The identifying assumption to generate the instruments is $E[\Delta\xi_{jm} \mid x_{jm}] = 0$, which again is a weaker assumption than the often used assumption $E[\xi_{jt} \mid x_{jm}] = 0$, when there are no modeled brand or market specific fixed effects. This assumption implies orthogonality of observed and residual unobserved product characteristics.

Following Berry et al. (1995) and the subsequent literature, I apply instruments, which are motivated through Nash markups in oligopolistic markets. Vehicles facing competition through close substitutes will be priced with low markups, while vehicles without this competition will have higher markups. At the same time, vehicles from own manufacturers will be treated differently than vehicles from competitors, which is why a distinction between own products and products of competitors seems appropriate. The following instruments will be applied: the observed nonprice vehicle characteristics x_{jm}, the sum of the nonprice attributes of other products by the same firm in the market and the sum of the nonprice attributes of other firms products in the same segment. Additionally the number of products by own and by other firms in the segment will be used as instruments.

5. Data

According to equation (12) from section 4, the market share (MS) of vehicle j in market m is dependent on the following components:

$$(13)\quad MS_{j,m} = f\left(x_{j,m}, ct_{j,m}, p_{j,m}, \bar{y}_m, esp_{j,m}, S_{\frac{j}{gm}}, \xi_b, \xi_m\right)$$

with x as a vector of vehicle characteristics, ct as the circulation tax, p as the price, esp as the expected scrappage premium, $S_{\frac{j}{g}}$ as the group share of vehicle j in group g, and brand and market fixed effects ξ_b, ξ_m. All variables vary over car model j and markets m.

In order to conduct the estimation on the model described in Section 4, an inventory of new vehicle registrations is required, that contains information about the number of registrations, vehicle characteristics including sales prices (adjusted for the scrappage premium, where applicable) and recurring vehicle costs as well as the vehicle circulation tax.

Information on monthly registration data by vehicle model and on some vehicle components such as engine displacement, power, emissions class, fuel economy and vehicle segment are obtained from the German Federal Motor Transport Authority KBA for the years 2007-2013 (KBA, 2014). More detailed vehicle characteristics, including sales price, weight and size of vehicles are available from a database provided by the German Automobile Club (ADAC, 2015) that contains vehicle characteristics for all vehicle models available on the German market between 2007 and 2015. This dataset, however, does not contain any sales data. The KBA and ADAC datasets are therefore matched on the basis of vehicle characteristics such as engine size, sales period, and model identification numbers, in order to combine registration information with detailed vehicle information, including sales prices that are not contained in the original KBA dataset. With this method, 93 per cent of the vehicle registered in Germany between 2007 and 2013 could be uniquely identified and matched. I now describe the data in more detail:

x is a vector of control variables that encompasses the following vehicle characteristics: $fuelcosts$, $performance$, $emissionclass$, $length$, $width$, $height$ and $weight$. Data on vehicle characteristics stems from the combined dataset described above, unless otherwise noted.

The variable $fuelcosts$ *[€ cents / 100 km]* is the product of fuel consumption (*consumption [liter / 100 km])* and the at-pump prices of fuel ($fuelprice$ *[€ cents / liter])*. Fuel prices ($fuelprice$)

were obtained from ADAC (2016) as monthly average prices for gasoline and diesel in Germany and assigned to a vehicle depending on engine type (Otto or diesel engine). Prices were not adjusted for inflation, since the nominal price enters the car buyer's decision at time of purchase. $consumption$ is taken from ADAC (2015) and describes vehicle-average fuel consumption (gasoline or diesel) when driving 100 km. The coefficient of $fuelcosts$ is expected to have a negative sign, since higher fuel prices lead to, ceteris paribus, higher costs for operating a vehicle, which will decrease vehicle demand and thus lower market shares for this vehicle (Leard at al. 2016).

As an indicator for a cars performance, the variable $performance$ *[kw*cc]* is used, which is an interaction of the variables $horsepower$ *[kw]* and $engine\_displacement$ *[cc]* and is expected to have a positive sign, as ceteris paribus, car buyers prefer higher performance vehicles (see Achtnicht, 2011 for results specific to Germany).

The variable $emissionclass$ *[Euro 3, Euro 4, Euro 5, Euro 6]* refers to the European Emission Standards, which define limit values for exhaust emissions of new vehicles admitted in the European Union that become binding over time. For example, the Euro 3 standard came into force in 2000, the Euro 6 standard in 2014. This dataset includes emission classes 3 to 6. Setting emission class 3 as the base variable and comparing the remaining emission classes 4, 5 and 6 to the base category, they are expected to have positive signs, since a higher emission class, even prior to becoming mandatory, not only leads to a reduction in health costs from road transportation - which might be discounted strongly by individual car buyers as gains are distributed over the population - but also gives permission to enter German Low Emission Zones (Malina and Scheffler, 2015). Thus, they are expected to be preferred, ceteris paribus, when purchasing a new car.

The variables $length$ *[cm]*, $width$ *[cm]*, $height$ *[cm]* and $weight$ *[kg]* control for dimensions and weight of the vehicle and their expected signs depend on specific preferences of purchasers throughout time. For Germany, there is ambiguous data with regard to the expected sign of the coefficients for the variables that describe the dimensions of the car. ADAC surveys (ADAC, 2012, 2013, 2014) indicate that German car buyers, on average prefer more spacious vehicles (i.e. combination of length, width and height), but the data is not broken out by the different dimensions. With regard to length, ARAL (2015) reports survey data that indicates, ceteris paribus, that buyers prefer cars that have lower length, which could be explained by better access to curbside parking in cities. Therefore, I expect a negative sign of $length$. No specific study is available on consumers' preference with regard to $width$; however, I expect its coefficient to be positive, as, on average, increased width leads to more in-vehicle space without inflicting on parking. As for car width, no data is available for consumer's preferences with regard to $height$; however I expect the coefficient of the variable to have a positive sign as higher cars, on average, have higher seating positions and therefore not only offer enhanced sight for the driver but also easier access for all passengers. The relatively strong increase in registrations for SUV's outlined in section 2 of the paper, which, on average, are higher than other vehicles, provides some support to this hypothesis, as well.

There are opposing factors that might influence the sign of the expected coefficient of the variable $weight$. One the one hand, higher $weight$ might lead to higher market shares, as relatively heavy vehicles are perceived to be more prestigious (Vance and Mehlin, 2009) and potentially safer for the occupants in case of accident (Kahane, 2012). On the other hand, insurance premiums are higher for heavier cars such as SUV's - due to higher propensity of being stolen (GDV, 2015) and higher accident and non-occupants fatality rates (Anderson and Aufhammer, 2013), which, ceteris paribus, decreases consumer preference for heavier cars. Taking these two factors together, I yield an ambiguous relationship between vehicle weight and market shares and, consequently, the overall sign of the relationship remains undetermined, a priori. Note that while higher weight leads to lower fuel economy and, therefore, higher fuel costs, this effect is already accounted through the $fuelcosts$ variable.

The coefficient of the variable circulation tax *(ct [€])* is expected to have a negative sign, since higher circulation tax increases the ownership costs of a vehicle, which should decrease demand and market share. The circulation tax is calculated according to the official tax rates of the German circulation tax law ("Kraftfahrzeugsteuergesetz", Bundesministerium der Justiz, 2016). To simplify the time period around the tax change, tax rates are calculated according to the old law before July 2009 and according to the reformed law starting from July 2009, abstracting from exemption rules that were in place for a transition period. Eventually, the vehicles for which the exemptions applied are taxed according to the reformed circulation tax. Since this information was available upon purchase during the transition period, it should influence the decision of which car to buy similar to as if the new vehicle circulation tax rate was paid right after July 2009.

Vehicle prices p *[€]* are the list prices of vehicles and are taken from the ADAC dataset. As with all monetary data used, nominal prices were used and not adjusted, because the nominal price enters the purchasers' decision at the time of the transaction. Prices are weighted by the monthly mean disposable income of households ($\bar{Y}_m$ *[€]*), in order to allow for restricted control of wealth effects with regard to car demand. Data on $\bar{Y}_m$ was collected from the continuous household budget surveys ("Laufende Wirtschaftsrechnung") of the German Federal Statistical Office (Statistisches Bundesamt, 2014). The missing years 2008 and 2013 were calculated by linear interpolation. The coefficient of the income-weighted price is expected to have a negative sign, as higher sales prices should, ceteris paribus, lower demand and market shares.

Data about the expected scrappage premium ($esp_{j,m}$ *[€]*) in 2009 was collected from the German Federal Office for Economic Affairs and Export Control (Bundesamt fuer Wirtschaft und Ausfuhrkontrolle, 2010). It contains the annual number of vehicles bought by using the scrappage premium, $Prem_{j,2009}$, classified by model. This information by model was matched with the existing dataset and weighted by the total number of registered new vehicle models j in 2009, $\sum_{m=1/2009}^{m=12/2009} J_{j,m} = J_{j,2009}$. $esp_{j,m}$ for 2009 can thus be defined as

(14) $$esp_{j,m} = \frac{Prem_{j,2009}}{J_{j,2009}} \times 2500.$$

Following the approach taken for the list price, $esp_{j,m}$ is weighted by $\bar{Y}_m$. The variable is interacted with a dummy, which takes the value of 1 for each month in 2009. Since $esp_{j,m}$ lowers the purchase price of a vehicle, its coefficient is expected to be positive, meaning the higher $esp_{j,m}$, the higher the demand and market share of a vehicle model.

$S_{\frac{j}{gm}}$ is the observed group share of vehicle j in group g and results from the data. The sign of the coefficient is positive, since a higher group share will lead to higher market shares. It is this linkage, that requires to instrument for $S_{\frac{j}{gm}}$.

Table 6 provides summary statistics for the variables used in the estimation.

Table 6: Summary statistics

Variable	[unit]	Obs	Mean	Std. Dev.	Min	Max
MS[1]		64,527	-8.2950	2.0724	-12.8276	-2.4498
ct[2]	[€]	64,524	212.6193	126.5013	14	946
esp[3]		64,527	0.0383	0.1316	0	0.8547
fuelcosts	[€ cents/ 100 km]	64,527	1019.44	354.369	335.61	2840.7
performance	[kw*ccm]	64,527	347,308.4	419,332.4	23,970	2,768,740
emissionclass 4[4]		64,527	0.4879	0.4999	0	1
emissionclass 5[4]		64,527	0.5006	0.5	0	1
emissionclass 6[4]		64,527	0.0108	0.1031	0	1
length	[cm]	64,527	4,424.2540	405.9533	2500	5,905
width	[cm]	64,527	1,790.1960	80.8703	1475	2,070
height	[cm]	64,527	1,527.3230	120.1621	1242.641	2,705
weight	[kg]	64,461	1,520.9750	326.8577	740	2,744
p[5]		64,527	11.5072	8.2836	2.1673	85.6511
$ln(S_{\frac{j}{gm}})$[6]		64,527	-6.6426	2.0934	-11.6857	-1.1958

Notes: [1]: Market Share, [2]: circulation tax, [3]: expected scrappage premium, weighted by income, [4]: Emissions class 3 is the base category with a mean of 0.0008, [5]: list price, weighted by income, [6]: observed group-share.

Additionally, the model contains brand fixed effects ξ_b and market fixed effects ξ_m. ξ_b controls for unobservable brand-specific vehicle characteristics, which might lead to consumers' preferences for certain brands that cannot be controlled for directly (Kressmann et al., 2006). Market fixed effects ξ_m capture unobserved phenomena, such as economic cycles, economic stimulus programs, or seasonal changes. An alternative model (not reported), which includes additional annual fixed effects in order to control for large scale phenomena separately, was estimated, but did not change estimates of the other parameters. Therefore, monthly fixed effects can be regarded to be appropriate control variables for larger scale phenomena.

Vehicles were assigned to the segments that were described in Chapter 2, namely: Mini =1, Small = 2, Lower Midrange = 3, Midrange = 4, Upper Midrange = 5, Large and Luxury = 6. No distinction between private and company cars was made in this paper as circulation tax is levied according to the same formula for both types of usage. Table 7 presents selected segment-specific summary statistics.

Table 7: Summary statistics for segments, 2007-2013

	Segments:	Mini	Small	Lower Midrange	Midrange	Upper Midrange	Large and Luxury
Market Share		0.07	0.20	0.28	0.16	0.05	0.24
CO_2 emissions	Weighted mean	116.24	133.92	143.63	155.42	169.96	170.61
[g/km]	Min	85.71	87.00	89.60	86.90	115.00	88.00
	Max	355.00	223.00	300.70	348.00	359.98	452.83
ct	Weighted mean	49.23	84.05	144.70	233.77	236.75	318.94
(circulation tax)	Min	14	18	20	20	72.4	18
[€]	Max	448.2	376.6	463.2	576	617.6	946
fuelcosts	Weighted mean	709.84	787.74	815.15	816.79	860.64	937.39
[€ cents]	Min	335.61	382.46	396.63	409.11	512.55	380.49
	Max	2173.6	1437.06	1915.8	2167.75	2351.52	2840.7
performance	Weighted mean	55,480.31	87,614.94	14,4968.6	24,9838.6	26,6687.4	40,7638.1
[kw*ccm]	Min	23,970	43,912	30,248	31,960	78,246	26,367
	Max	2,396,288	599,200	1,665,280	2,251,780	2,396,288	2,768,740
emissionclass 3		0.0	0.0	0.0	0.0	0.0	0.2
emissionclass 4	Weighted mean	54.28	53.47	51.79	50.51	51.41	43.63
emissionclass 5	percentage share	45.13	46.42	47.47	48.37	46.9	54.64
emissionclass 6		0.59	0.11	0.74	1.12	1.69	1.53
length	Weighted mean	3,474.74	3,960.541	4,313.514	4,461.942	4,664.926	4,875.333
[cm]	Min	2500	3395	2985	2695	3740	2695
	Max	5905	5292	5413	5179	5223	5267
width	Weighted mean	1619.989	1696.38	1776.341	1812.186	1816.986	1853.629
[cm]	Min	1475	1475	1495	1559	1680	1559
	Max	1993	1974	2050	1922.281	1921.078	2070
height	Weighted mean	1,457.855	1,475.828	1,483.994	1,499.755	1,512.352	1,624.763
[cm]	Min	1,385	1,245	1,245	1,291	1,287	1,242.641
	Max	2,476	2,476	2,524	1,959	1,900	2,415
weight	Weighted mean	957.6136	1,133.08	1,354.677	1,572.84	1,610.387	1,775.053
[kg]	Min	740	890	810	845	1050	845
	Max	2,185	2,093	2,265	2,433	2,135	2,744
Price[1]	Weighted mean	11,891.88	15,739.9	22,861.79	33,952.12	34,301.77	48,128.68
[€]	Min	7,190	8,990	6,790	9,640	14,160	9,990
	Max	161,483	49,900	86,800	130,000	112,888	268,345

Notes: [1]: price denotes actual list price of vehicle.

Overall, I obtain an unbalanced panel dataset observing registrations of new passenger cars over a period of 84 months (January 2007 to December 2013), where observations are defined by year, month and vehicle specification. The vehicle specification distinguishes unique vehicle models by information about manufacturer, model name, model identification number, market segment, vehicles characteristics (fuel costs, performance, emissions class, vehicle length, width, height and weight), circulation tax, sales price, expected scrappage premium and market share. In total, the vehicle inventory contains 6,867 unique vehicle models and 19,483,518 new vehicle registrations.

6. Results and Interpretation

The model is estimated using STATA 13.1. A Pagan-Hall test for heteroskedasticity was implemented, which rejected the null hypothesis of no heteroskedasticity. Therefore Standard Errors were adjusted to arbitrary heteroskedasticity. Post estimation, the instruments are tested for underidentification, weak identification and overidentification. Results from the Kleibergen-Paap rk LM statistic lead to the conclusion that the instruments are correlated with the endogenous regressor and thus are relevant. The Kleibergen-Paap rk Wald F statistic does not suggest existence of weak instruments. The J statistic of the Hansen Test of overidentification leads to reject the null hypotheis of overidentification. Therefore the model is identified and the instruments are relevant. Test statistics for instruments tests are reported in appendix A2.

Table 8, column 3 displays the estimation results for the core variables using the nested logit specification. The entries depict parameter estimates as well as estimated robust standard errors in parentheses. Results for the brand dummies are presented in the Appendix.

The coefficients of the control variables show the expected signs and are statistically different from zero at the 0.1 per cent level. Higher relative income-weighted vehicle prices *p*, ceteris paribus, decrease market shares, as do higher *fuel costs* and higher vehicle *length*. Higher performing vehicles (*performance*) show higher market shares, as well as *higher* and *wider* vehicles and vehicles that belong to more stringent *emission classes*. Vehicle *weight*, for which previously an ambiguous relationship with market share was discussed, is found to be negatively associated with market shares. This might imply that the effect from higher insurance premiums for heavier cars dominate other factors that might influence how vehicle *weight* impacts on vehicle market shares such as perceived safety superiority.

As expected, manufacturers' brands do significantly impact on vehicle market shares. Compared to cars sold under the Volkswagen brand (which was chosen as point of comparison as highest selling car manufacturer in Germany), a car made by foreign manufacturers, ceteris paribus, have significantly lower market shares. At the 5 per cent significance level, there is no significant difference of the influence on market shares from VW and the other German manufacturers BMW and Mercedes. Vehicles manufactured by Porsche and Audi, ceteris paribus, have a significantly higher impact on market shares than VW, whereas vehicles manufactured by Opel have a significantly lower effect on market shares. Results for all manufacturers are provided in the Appendix.

Table 8: Estimation results, standard errors in parentheses

Variable	Variable explanation	Nested Logit Coef.	Logit Coefficient
p	List prices weighted by income levels	-0.0209062***	-0.0485913***
		(0.005893)	(0.0068505)
ct	Annual circulation tax payable for a vehicle [€]	-0.0008501***	-0.0010673***
		(0.0000914)	(0.0001099)
esp	Expected scrappage premium [€]	0.7289452***	0.694415***
		(0.0733004)	(0.0892029)
fuelcosts	Fuel costs [€ cents]	-0.0019596***	-0.0024286***
		(0.0000428)	(0.0000364)
performance	Interaction of engine size and power [cm*kw]	3.87E-07***	8.11e-07 ***
		(8.42E-08)	(9.70e-08)
emissionclass 4	Vehicle classified as EURO 4 standard	0.8150828***	0.942436***
		(0.1397807)	(0.1718177)
emissionclass 5	Vehicle classified as EURO 5 standard	1.955426***	2.340249***
		(0.1431029)	(0.1737142)
emissionclass 6	Vehicle classified as EURO 6 standard	2.030211***	2.440748***
		(0.1537664)	(0.1865943)
length	Vehicle length [cm]	-0.0003698***	-0.0003461***
		(0.0000378)	(0.0000456)
width	Vehicle width [cm]	0.004749***	0.0050419***
		(0.0001898)	(0.0002306)
height	Vehicle height [cm]	0.0020324***	0.0022494***
		(0.0000805)	(0.0000963)
weight	Vehicle weight [kg]	-0.0011972***	-0.0012751***
		(0.0000761)	(0.0000926)
$\boldsymbol{ln}(S_{\frac{j}{gm}})$	Ln(groupshare)	0.182268***	-
		(0.0118876)	-
R^2 (centered)		0.58	0.38

Notes: *** significant at 0.1 % level.

For the vehicle circulation tax, *ct*, the main variable of interest, I find a statistically significant negative relationship with market shares. As expected, ceteris paribus, higher vehicle circulation tax leads to lower market shares. I also compare the nested logit results to results obtained with a simple logit specification, in which no nests according to market segments are formed. The results for the logit specification are provided in column 4 of Table 8. This comparison shows that the use of the simple logit model would have lead to an upward bias in coefficient estimates, with, for example, the coefficient for income-weighted vehicle price being twice as high in the simple logit specification. Moreover, the nested logit specification shows considerably higher goodness of fit, with an R^2 of 0.58 vs. 0.38 for the simple logit model.

I now quantify the effect of the change in vehicle circulation tax on CO_2 emissions and climate costs from road transportation. This effect is a result of two factors: First, the tax reform might have impacted on the composition of new registrations *within* each market segment that, in turn, changes the average

CO_2 emissions index (in g CO_2/km) in the segment. Second, the tax might have influenced the number of new registrations of each market segment, thereby influencing market shares *between* the segments. As mentioned in section 2, the CO_2 component of the vehicle circulation tax becomes more stringent over time, consequently, I simulate the environmental effect of the least-stringent tax formula of 2010 as well as the effect of the most-stringent tax formula that was introduced in 2014.

In order to capture both effects, I first simulate changes in new registrations within each segment induced by the change in vehicle circulation tax, by using model-specific estimates for market share elasticity with regard to vehicle circulation tax derived from the estimation. I then calculate the resulting change of average CO_2 emissions in each segment (CO_2 emissions index) by subtracting the average CO_2 emissions index within segment, which is weighed by the simulated number of registrations for each vehicle, from the actual (2008) CO_2 emissions index for each segment. Finally, I multiply the change in CO_2 emission index with the number of vehicles in each segment and segment-specific annual distance travelled by vehicle. This yields the total change in CO_2 emissions from changes in model composition *within* each segment.

To account for the impact of changes in market shares *between* segments, I then multiply the number of additional / fewer registrations by each segment obtained from the calculations above with the simulated CO_2 emissions index and segment-specific annual distance travelled by vehicle. This yields total CO_2 emission changes due to changes in market shares between segments.

Finally, changes in CO_2 emissions from both effects are monetized using estimates for the societal damages from CO_2 emissions. In order to separate the effect of the change in vehicle circulation tax from confluent or counteracting factors that influence CO_2 emissions from passenger cars such as technology improvements, or EU tailpipe CO_2 regulation changes, I simulate the vehicle circulation tax impact as ceteris paribus variation for the composition of new vehicle registrations in 2008, the last full year under the old taxation scheme.

Overall, the approach to calculate the total change in monetized climate damages from road transportation due to the vehicle circulation tax reform can be written as follows:

(15) $$\Delta TC = \left(\sum_{s=1}^{6}(VNsim_{s,k} \times EIsim_{s,k} - VN_{s,2008} \times EI_{s,2008}) \times VK_s\right) \times DC$$

with

(16) $$VNsim_{s,k} = VN_{s,2008} \times E_{MS,s} \times \frac{ctsim_{s,k}}{ct_{s,2008}} + VN_{s,2008}$$

and

(17) $$EIsim_{s,k} = \sum_{j=1}^{N}\left(\left(VN_{j,2008} \times E_{MS,j} \times \frac{ctsim_{j,k}}{ct_{j,2008}} + VN_{j,2008}\right) \times EI_{j,2008}\right) / VNsim_{s,k}$$

with ΔTC as total change in damage costs across all segments, $VNsim_{s,k}$ as simulated number of registrations, $EIsim_{s,k}$ as simulated CO_2 emission index (in g CO_2/km) and $ctsim_{s,k}$ as simulated total vehicle circulation tax payable, all for segment *s* using the tax formula from year *k* (2008 or 2014, respectively). VM_s denotes the average annual distance travelled by car in segment *s* (in km). $VS_{s,2008}$ are the actual number of registrations in each market segment and $EI_{s,2008}$ are the actual emission indices by segment in 2008, $E_{MS,s}$ is the elasticity of market share with regard to vehicle circulation tax, and $ct_{s,2008}$ is the total vehicle circulation tax payable in 2008 in segment *s*. Parameters with the subscript *j* denote vehicle-model specific parameters.

Changes in the CO_2 emission index capture the effect of the circulation tax reform *within* segments, whereas changes in the number of registrations by segment capture the effect *between* segments, as outlined above.

Table 9 displays the estimates for the elasticity of market shares with regard to vehicle circulation tax and corresponding standard errors, broken out by market segment. Elasticity (in absolute values) increases with higher vehicle segments (S1 to S6). For example, the elasticity of market shares with regard to circulation tax in Segment 6 is approximately three times as high as in Segment 1. Note that a 1 per cent change in vehicle circulation tax represents an increase of approximately € 0.5 for Segment 1 and of approximately € 3 for Segment 6 (see descriptive statistics in Table 6). This implies - as expected - that customers in more expensive vehicle segments are less sensitive to a certain absolute change in vehicle circulation tax than customers in lower segments.

Table 9: Elasticities of market shares with regard to circulation tax, by segment

	Mini (S1)	Small (S2)	Lower Mid-range (S3)	Midrange (S4)	Upper Mid-range (S5)	Large and Luxury (S6)
Estimate	-0.0084144	-0.0124517	-0.0170872	-0.0220273	-0.0274972	-0.027504
Standard Error	0.0009045	0.0013395	0.0018383	0.0023671	0.0029492	0.0029594

Notes: Standard Errors are estimated by delta method.

Vehicle registration data are taken directly from my dataset that is based on the official KBA actual registration information. Changes in vehicle circulation tax are calculated by applying the tax formulae for the relevant years to the different models in the vehicle database. For annual distance travelled by car and segment, results from the German national mobility survey ("Mobilität in Deutschland"), conducted in 2008 (BMVBS, 2009), are used. While uncertainty is present on the degree to which the survey results match actual distance traveled by car and segment, no data exists that would allow for quantifying this uncertainty, and consequently, the parameter is treated deterministically. I address uncertainty in the elasticity of market shares with regard to the vehicle circulation tax, segment-specific CO_2 emissions, and the monetization of climate damages. Elasticity uncertainty is directly taken from the results of the nested logit estimation. For the CO_2 emission index by segment, there is well-established evidence that actual on-road CO_2 emissions of passenger cars in Europe can be higher than the values provided by manufacturers from test stand combustion emission tests (e.g. Ntziachristos et al., 2014), because European regulation provides loopholes for test conditions to deviate from real-world driving conditions (Tietge et al., 2015). As fuel economy is not only a relevant driver of purchasing decisions, but is also subject to increasingly tight limit values at the EU level (European Union, 2014), this provides incentives to car manufacturers to report the lowest fuel economy measurements possible. However, the actual magnitude of the difference of test stand results and on-road emissions is uncertain. I account for this uncertainty by using the manufacturer estimates as low bound of a triangular distribution and by, respectively, using markups derived from ADAC and SPRITMONITOR on-road estimates for mode and high-bound, as documented in Mock et al. (2012).

Finally, a wide body of literature exists on the uncertainty of the monetary damages induced by climate change brought about by CO_2 emissions (see for an overview Tol, 2012). I use a normal probability density function for CO_2 damage costs derived from a simplified global climate model (APMT) developed and maintained at the Massachusetts Institute of Technology (Mahashabde et al., 2011; Trivedi et al., 2015). This function is converted into Euro using a 2010 $ / € purchasing power parity (PPP) of 0.79034 (OECD, 2016), yielding a mean estimate of € 32.8 / tCO_2 (USD 41.5 / tCO_2) and a standard deviation of € 17.7 / tCO_2 (95 per cent confidence interval € 16.7 to 52.4). For comparison purposes, in a recent analysis the European Energy Agency (EEA, 2014b) used damage costs per ton of CO_2 of € 10 and 40, respectively, and the 2010 PPP adjusted central estimate used by the US government in regulatory assessments is € 41.6 / tCO_2 (IAWG, 2016).[4] Used parameter values and probability distributions for uncertain parameters for the Monte Carlo analysis are provided in Table 10. Table 11 summarizes the deterministic parameter values used.

I use the parameter values and their probability distributions from Table 10, and the deterministic values in Table 11 in a stochastic analysis using Monte Carlo techniques, in which the parameters are sampled randomly from their probability distributions for 10,000 simulations. Median results and standard deviations of the change in registrations, change in CO^2 emission index, change in CO_2 emissions and change in climate costs of road transportation are provided in Table 12, broken out by segments. For both tax formulae - the least stringent CO_2 based tax regime from 2010 and the most stringent from 2014 – the table shows that, ceteris paribus, the vehicle tax reform has had only relatively small impacts on all metrics of interests.

[4] Value calculated for a 2.5 per cent discount rate for damages. The discount rate assumed is not explicit in EEA (2014). APMT applies a discount rate for future climate damages from present day CO_2 emissions of 2 per cent.

Table 10: Descriptive statistics and data sources for uncertain parameters in Monte-Carlo Analysis

Parameter	Distribution (mean; standard error) or (low, mode, high) or value	Data source and comments
Market share elasticity with regard to vehicle circulation tax, by segment		
Segment 1	$E_{MS,S=1} \sim$ N (-0.0071128, 0.0008253)	Own calculation from nested logit estimation
Segment 2	$E_{MS,S=2} \sim$ N (-0.0111892, 0.0012992)	
Segment 3	$E_{MS,S=3} \sim$ N (-0.0157229, 0.0018255)	
Segment 4	$E_{MS,S=4} \sim$ N (-0.0202699, 0.0023512)	
Segment 5	$E_{MS,S=5} \sim$ N (-0.0253451, 0.0029345)	
Segment 6	$E_{MS,S=6} \sim$ N (-0.0253670, 0.0029457)	
CO_2 emissions index, by segment (in g CO_2/km), 2008 actuals		
Segment 1	$EI_{S=1,2008} \sim$ Tr (121.7579; 131.4985; 141.2392)	Own calculations based on KBA (2014) and ADAC (2015)
Segment 2	$EI_{S=2,2008} \sim$ Tr (142.6006; 154.0145; 165.4230)	
Segment 3	$EI_{S=3,2008} \sim$ Tr (154.6529; 167.0251; 179.3974)	
Segment 4	$EI_{S=4,2008} \sim$ Tr (166.5034; 179.8237; 193.1439)	
Segment 5	$EI_{S=5,2008} \sim$ Tr (190.5060; 205.7465; 220.9870)	
Segment 6	$EI_{S=6,2008} \sim$ Tr (188.8460; 203.9537; 219.0614)	
CO_2 emissions index, by segment (in g CO_2/km), simulated with 2010 tax		
Segment 1	$EI_{S=1,2008} \sim$ Tr (121.7439; 131.4834; 141.2229)	Own calculation based on from nested-logit mod-el, and Mock et al. (2012)
Segment 2	$EI_{S=2,2008} \sim$ Tr (142.5709; 153.9766; 165.3822)	
Segment 3	$EI_{S=3,2008} \sim$ Tr (154.5660; 166.9313; 179.2966)	
Segment 4	$EI_{S=4,2008} \sim$ Tr (166.3824; 179.6930; 193.0036)	
Segment 5	$EI_{S=5,2008} \sim$ Tr (190.3436; 205.5711; 220.7986)	
Segment 6	$EI_{S=6,2008} \sim$ Tr (188.6492; 203.7411; 218.8331)	
CO_2 emissions index, by segment (in g CO_2/km), simulated with 2014 tax		
Segment 1	$EI_{S=1,2008} \sim$ Tr (121.7234; 131.4613; 141.1991)	Own calculation based on from nested-logit mod-el, and Mock et al. (2012)
Segment 2	$EI_{S=2,2008} \sim$ Tr (142.5658; 153.9711; 165.3763)	
Segment 3	$EI_{S=3,2008} \sim$ Tr (154.5650; 166.9302; 179.2954)	
Segment 4	$EI_{S=4,2008} \sim$ Tr (166.3897; 179.7009; 193.0121)	
Segment 5	$EI_{S=5,2008} \sim$ Tr (190.3528; 205.5810; 220.8092)	
Segment 6	$EI_{S=6,2008} \sim$ Tr (188.6545; 203.7469; 218.8392)	
Damage cost per ton of CO_2 (in EUR)	$DC_{CO2} \sim$ N (32.78; 17.62)	Trivedi et al. (2015)

Notes: Tr denotes triangular distribution.

Table 11: Descriptive statistics and data sources for deterministic parameters in Monte-Carlo Analysis

Parameter	Value		Data source and comments
Number of registrations by segment (in 2008)			
Segment 1	$VN_{S=1}$=184,983		Own calculation based on KBA (2014)
Segment 2	$VN_{S=2}$=553,545		
Segment 3	$VN_{S=3}$=819,983		
Segment 4	$VN_{S=4}$=534,475		
Segment 5	$VN_{S=5}$=148,328		
Segment 6	$VN_{S=6}$=653,823		
Percentage change in total vehicle circulation tax accrued, by segment			
	2010 vs. 2008 formula	2014 vs. 2008 formula	
Segment 1	$\frac{ctsim_{1,2010}}{ct_{1,2008}}$ =-48.6 %	$\frac{ctsim_{1,2014}}{ct_{1,2008}}$ =-1.0 %	Own calculation based on KBA (2014) and ADAC (2015)
Segment 2	$\frac{ctsim_{2,2010}}{ct_{2,2008}}$ =-19.9 %	$\frac{ctsim_{2,2014}}{ct_{2,2008}}$ =25.7 %	
Segment 3	$\frac{ctsim_{3,2010}}{ct_{3,2008}}$ =-10.6 %	$\frac{ctsim_{3,2014}}{ct_{3,2008}}$ =17.0 %	
Segment 4	$\frac{ctsim_{4,2010}}{ct_{4,2008}}$ =-6.0 %	$\frac{ctsim_{4,2014}}{ct_{4,2008}}$ =13.2 %	
Segment 5	$\frac{ctsim_{5,2010}}{ct_{5,2008}}$ =-2.1 %	$\frac{ctsim_{5,2014}}{ct_{5,2008}}$ =11.7 %	
Segment 6	$\frac{ctsim_{6,2010}}{ct_{6,2008}}$ = 8.7 %	$\frac{ctsim_{6,2014}}{ct_{6,2008}}$ =28.6 %	
Average distance driven per vehicle in 2010, by segment (in km)			
Segment 1	$VD_{S=1}$=11,120		Own calculations based on BMVBS (2009) and KBA (2014)
Segment 2	$VD_{S=2}$=11,797		
Segment 3	$VD_{S=3}$=14,198		
Segment 4	$VD_{S=4}$=16,230		
Segment 5	$VD_{S=4}$=17,409		
Segment 6	$VD_{S=5}$=16,615		

Table 12: Change in registrations, change in CO_2 emission index, CO_2 emissions and climate costs attributable to the vehicle tax reform, by vehicle segment

	Δ Registrations				Δ Emissions Index (in %)				Δ CO_2 (in t)				Δ Climate costs (in 1,000 EUR)			
Segment	2010 formula		2014 formula		2010 formula		2014 formula		2010 formula		2014 formula		2010 formula		2014 formula	
	Md	SD	Md	SD	Md	SD	Md	SD	Md	SD	Md	SD	Md	SD	Md	SD
S 1	539	63	11	1	-0.01	0.00	-0.03	0.00	903	112	-58	3	29	16	-2	1
S 2	1,109	129	-1,436	167	-0.02	0.00	-0.03	0.00	1,920	257	-3,073	339	62	35	-99	55
S 3	1,271	148	-2,036	237	-0.06	0.00	-0.06	0.00	2,151	382	-6,284	635	69	40	-204	113
S 4	622	72	-1,371	159	-0.07	0.00	-0.07	0.00	764	221	-5,247	512	23	16	-170	95
S 5	65	8	-363	42	-0.09	0.00	-0.08	0.00	-169	33	-2,002	193	-5	3	-65	36
S 6	-1,320	153	-4,336	504	-0.10	0.00	-0.10	0.00	-7,191	606	-18,274	1,956	-235	129	-591	331
TOTAL	2,286	265	-9,527	600	-0.08	0.00	-0.08	0.00	-1,620	797	-34,960	2,138	-47	41	-1,144	621

Notes: Md: Median; SD: Standard Deviation. Values calculated by simulating changes in metrics if applying 2010 and 2014 tax formulae, respectively, instead of 2008 formula.

The initial change in taxation in 2010 lead to a relatively small reduction in registrations in the segment with the highest CO_2 emissions (segment 6, ~1,300 vehicles, 0.2 per cent of registrations) that, however, is overcompensated by increases in registrations in all other segments, so that mean total registrations increase by approx. 2,300 vehicles, or 0.1 per cent of all new registrations in 2008. Note that segment-specific changes in registrations are a function of changes in registrations of individual models within each segment. For example, in segment 4, of the 240 models in this segment, 190 models are sold less because they require higher tax payments under the tax reform for a total reduction of 2,700 vehicles, while 50 models are sold more for a total of ~3,300 additional vehicles, yielding a net increase in approx. 600 vehicles sold. Changes in registrations within segments, while larger then changes between segments, are still relatively small, accounting for less than 1 per cent of all vehicles sold within a segment. These changes in the composition of new registrations within each segment are captured in changes in the segment-specific CO_2 emission index, that decreases for all segments. However, across all segments, median percentage changes in CO_2 emission index only range from -0.01 to -0.1 per cent, with a median value of -0.08 per cent for all registrations. The net increase in registrations and net decrease in emission index translate into a relatively small decrease in total CO_2 emissions (median value of ~1,600 t, 90 per cent confidence interval: 300 to 3,000 t) and a relatively small decrease in total climate costs (median value of ~€ 50,000, 90 per cent confidence interval: € 0 to 130,000). Overall, this translates into a median reduction of CO_2 emissions and climate costs from newly registered passenger vehicles of approximately 0.02 per cent.

When applying a ceteris paribus variation of the vehicle circulation tax based on the 2014 formula compared to the one from the year 2008, I find that median registrations in all segments but segment 1 (Mini) decrease slightly (by ~400 to 4,300 vehicles by segment, or 0.3 to 0.9 per cent of all new registrations by segment, at the median). Overall median registrations are estimated to decrease by approx. 9,500 vehicles, or 0.3 per cent. Note again that segment-specific changes are a function of changes in registration of individual vehicle models within each segment, which, as in case of simulating the effect of the 2010 tax regime, lead to a relatively small reduction of segment-specific CO_2 emission indices (0.03 to 0.1 per cent across segments). The reduction in new registrations and reduction in CO_2 emission indices when the 2014 tax formula is applied to 2008 vehicle models, decrease median CO_2 emissions from newly registered vehicles in 2008 by 35,000 t (90 per cent confidence interval: 31.000 to 39.000 t), and climate costs by € 1.1 Million (90 per cent confidence interval: € 0.1 to 2.2 Mio.), or 0.4 per cent of total CO_2 emissions and climate costs from newly registered cars. Overall the results show that effects from applying the more-stringent 2014 tax formula leads – as expected – to larger decreases in emissions and climate costs, however, these effects are still relatively small.

7. Conclusions

In this paper I estimate the effect of CO_2 based vehicle circulation taxation in Germany on annual CO_2 combustion emissions from passenger cars using a nested logit approach. This approach first yields vehicle segment-specific estimates for the elasticity of new vehicle registrations with regard to the circulation tax. These elasticities are used to estimate changes in new vehicle registrations which are then combined with vehicle-specific CO_2 emission factors and annual distances driven to yield total emission changes attributable to the change in vehicle circulation tax. Finally, physical changes in emissions are converted into changes in monetary climate damages using estimates for the social costs of carbon. Uncertainty in the elasticity of new vehicle registrations with regard to vehicle circulation tax, CO_2 emission indices of individual vehicle models and in the social costs of carbon are propagated through the analysis. I find statistically significant, but small changes in vehicle registrations due to the change in taxation. Overall, when simulating the most stringent CO_2 based taxation formula introduced in 2014 on the 2008 vehicle models, median new registrations are estimated to decrease by approximately 9,500 vehicles and the median market-wide CO_2 emission index are estimated to decrease by approximately 0.1 per cent. This leads to a median decrease of CO_2 combustion emissions from passenger cars of approximately 35,000 t, which are valued at € 1.1 million, or 0.4 per cent of total CO_2 climate costs from the use of newly registered vehicles. I note that the change in vehicle circulation tax only impacts fleet-wide emissions by changing new registrations, which means that the relative effect of the change in vehicle circulation tax on fleet-wide emissions are even lower than the relative impacts on new registrations calculated in this paper, until the fleet has been fully replaced with vehicles under the new taxation regime. For example, when using the CO_2 damage cost function applied in this paper on the 2008 vehicle fleet of approximately 41 million passenger vehicles (KBA 2009), median climate costs from the 2008 fleet amount to € 4 billion, which the vehicle circulation tax reform reduced by approximately 0.02 per cent.

I close by noting that there might be rebound effects stemming from the increased use of more fuel-efficient cars with lower variable costs that might further diminish emission benefits from the change in vehicle circulation tax. A recent study by Frondel et al. (2012), for example, estimates that a one percent increase in fuel efficiency, ceteris paribus, leads to a mean increase in road transport demand by 0.62 per cent. The analysis presented here estimates the direct effect of change in vehicle circulation tax under ceteris paribus conditions, that is without a change in driving behavior induced by changes in fuel economy which, in turn, have been induced by the change in vehicle circulation tax. An inclusion of these indirect effects on emission would further diminish reduction of tailpipe emissions attributable to the change in vehicle circulation taxation in Germany.

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Appendix

Table A1**:** Estimation results for coefficient of brand dummy variables, nested logit specification

Manufacturer	Coefficient estimate	P>|z|
Alfa Romeo	-1.51399***	0.000
Audi	0.0657248**	0.029
BMW	0.0452197	0.170
Cadillac	-1.789335***	0.000
Chevrolet	-1.35706***	0.000
Chrysler	-1.67709***	0.000
Citroen	-1.329761***	0.000
Dacia	-0.7481304***	0.000
Daihatsu	-1.703544***	0.000
Dodge	-0.6146072***	0.000
Fiat	-1.665862***	0.000
Ford	-0.6267136***	0.000
GM	-1.525921***	0.000
Honda	-1.018325***	0.000
Hyundai	-1.608538***	0.000
Infiniti	-1.627111***	0.000
Jaguar	-1.218178***	0.000
Jeep	-0.9465751***	0.000
Kia	-1.328893***	0.000
Lada	-1.615336***	0.000
Lancia	-2.90778***	0.000
Land Rover	-0.4448855***	0.000
Lexus	-2.054756***	0.000
Mazda	-0.688086***	0.000
Mercedes	-0.0599578	0.073
Mini	0.513706**	0.048
Mitsubishi	-1.227053***	0.000
Nissan	-0.9265428***	0.000
Opel	-0.4666253***	0.000

Peugeout	-1.205835***	0.000
Porsche	0.5538527***	0.000
Renault	-0.9653521***	0.000
Saab	-1.621529***	0.000
Seat	-0.7190108***	0.000
Skoda	-0.4285131***	0.000
Smart	-2.142741***	0.000
Ssangyong	-1.961726***	0.000
Subura	-1.323485***	0.000
Suzuki	-1.107926***	0.000
Toyota	-1.120474***	0.000
Volvo	-1.830166***	0.000

Notes: The brand *Volkswagen* is the base category to which results are to be compared.
*** significant at 0.1 % level, ** significant at 0.5 % level, grey background highlights German manufacturers.

Table A2: Test statistics for weak instruments test

Underidentification test:	
Kleibergen-Paap rk LM statistic	3423.468
Chi-sq(17) P-val = 0.0000	
Weak identification test:	
Kleibergen-Paap rk Wald F statistic[a]	243.207
Overidentification test of all instruments:	
Hansen J statistic	1112.363
Chi-sq(16) P-val = 0.0000	

Notes: [a] The critical values are the Stock-Yogo critical values for the Cragg-Donald F statistic.