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Environmental effects of a vehicle tax reform: empirical evidence from Norway*

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Abstract

In 2007, the Norwegian government reformed the vehicle registration tax in order to reduce the carbon intensity of the new car fleet by incentivizing the purchase of more fuel efficient cars. This paper identifies the impact of the new tax structure on three main dimensions: (i) the average CO_2 emissions intensity of new registered vehicles, (ii) the relative change in sales between low and high polluting cars and (iii) the market share of diesel cars. A Difference in Difference approach is employed to estimate the short run effects on each outcome variable of interest. The results show that the average CO_2 intensity of new vehicles was reduced in the year of the implementation of the reform by about 7.5 g of CO_2/km. This reduction is the result of a 12 percentage points drop in the share of highly polluting cars and of an increase of about 20 percentage points in the market share of diesel cars.

Keywords: CO_2 emissions intensity, New vehicles, Vehicle registration tax, Tax reform, Norway, Diesel.

JEL: H25, L62, Q51, Q53, Q54, R48.

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1 Introduction

Reducing automobile greenhouse gasses and pollutant emissions is a critical step to mitigate climate change. The transportation sector, which produces 23% of world energy-related CO_2 emissions, is the second-largest sector of energy consumption. Almost three quarters of transport emissions come from road transport, specifically passenger cars and light-duty trucks.[1] There are many approaches to reducing transportation emissions including the development of more fuel-efficient vehicles; the use of alternative fuels that come from renewable resources such as biofuel, hydrogen, and electricity; and the reduction of demand for vehicle travel by, for example, improving public transportation or bike lanes. In practice, the most widely used economic incentives for reducing road transport emissions fall into two categories: "command and control" regulation, such as emissions standards, and market-based incentives, such as fiscal instruments like carbon taxes. These approaches are interconnected and complement each other. The European Commission, for instance, has set CO_2 emissions targets for manufacturers specifically directed at new passenger cars to improve fuel efficiency through technological development.[2] At the same time, EU-Member States are individually implementing diverse fiscal measures including vehicle taxes to encourage the purchase of new vehicles with lower CO_2 emissions, and fuel taxes or circulation taxes, to control transportation activities.[3]

This study assesses the effects of a policy reform implemented by the Norwegian government in 2007 and designed to influence the demand for passengers cars. This reform focused on the Vehicle Registration Tax (VRT), which is an upfront tax for new vehicles, and accounts for about half the retail price. The government explicitly indicated that the objective of the reform was to reduce the intensity of CO_2 emissions of the average car fleet by incentivizing the purchase of more fuel-efficient cars.[4] The reform substituted the engine size component of the registration tax with the CO_2 emissions intensity component increasing the sensitivity of the tax to CO_2 emissions. As a consequence, consumers who purchased vehicles at the more efficient end of the distribution save about 10,000 NOK, while those who opt for relatively fuel-inefficient vehicles face an increase of about 50,000 NOK.

[1] International Energy Agency IEA (2009) and IPCC report by Kahn Ribeiro et al. (2007).

[2] Targets are: 130 g of CO_2 per km for the average new car fleet by 2015 and 95 g of CO_2 per km by 2020. Regulation (EC) No 443/2009 and No 333/2014 of the European Parliament.

[3] See van Essen (2012) for an overview of carbon-based vehicles taxation schemes in the European Union.

[4] The CO_2 emissions intensity is a measure based on the expected grams of CO_2 that a vehicle will produce per kilometer driven and it is measured in gCO_2/km.

What are the environmental effects of calculating the vehicle registration tax on CO_2 emissions intensity in Norway? To answer this question, a Difference in Differences (DID) approach is used to identify the short-run impact of the 2007 reform on three main outcome variables: 1) the average CO_2 emissions intensity of new registered vehicles, 2) the relative change between low and high CO_2 emitting cars and 3) the market share of diesel cars.[5] This reduced-form approach offers a clear and simple identification of the response parameters of interest and is particularly well-suited for establishing causality (Timmins and Schlenker (2009)).[6] The choice of method is appropriate because of the quasi-experimental nature of the phenomenon of interest. Other studies that have used reduced-form models to investigate related problems in different countries are Klier and Linn (2012), Klier and Linn (2013), Klier and Linn (2010), Hastings (2004) and Busse et al. (2006). The main data are provided by the Norwegian Road Federation OFVAS and contain repeated cross sections of new vehicles' monthly registrations in each municipality in Norway.[7]

The results suggest that the fiscal change induced a reduction of about 7.5 gCO_2/km in the average CO_2 performance of new cars in 2007, which corresponds to 4.3% decrease from the pre-treatment average and account for about 20% of the standard deviation. Between 2006 and 2007 the average CO_2 intensity of the new car fleet dropped from 173 to 160 gCO_2/km. The estimated causal impact of the reform, net of the anticipation effects, corresponds to about half of the overall reduction in the observed CO_2 intensity, which includes exogenous factors such as fuel efficiency improvements associated with the supply side of the market (Figure 1). The estimated reduction in CO_2 intensity is the combined result of a shift in demand toward greener vehicles and an increase in the market share of diesel cars. Specifically, the tax reform caused a reduction of about 12 percentage points in the share of high emitting vehicles, i.e. those emitting more than 180 gCO_2/km, and an expansion between 19 and 21 percentage points of the share of diesel cars within the year of the reform. Furthermore, no significant change in the number of new sales is found indicating that the VRT reform has mainly induced substitution effects.

When using a fiscal instrument to reduce CO_2 emissions, it is critical to assess its effectiveness. Examples of such instruments include feebates, vehicle registration taxes, circulation taxes and fuel taxes. The use of these instruments for climate policies has become increasingly popular, but they have been implemented very differently by different countries. As a consequence, evidence

[5] The effects are estimated over a nine-month period within the year of the intervention.

[6] This study aims to complement the large body of literature which makes use of structural models such as Bresnahan (1987); McCarthy (1996); Berry et al. (1995). Generally, these models do not focus primarily on vehicle taxes.

[7] Opplysningsrådet for Veitrafikken AS (OFV AS) http://ofvas.no/

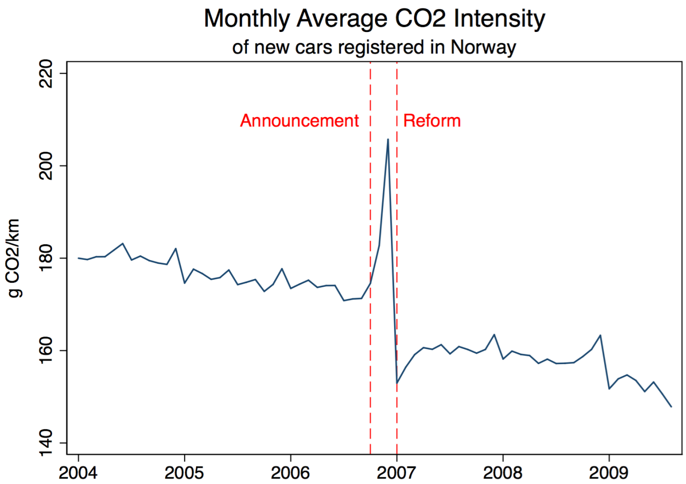

Figure 1: Monthly average CO_2 intensity of new vehicles registered in Norway between January 2004 and December 2011.

of their economic and environmental effects is complex to assess and sometimes conclusions are conflicting (Mandell (2009)). Some studies argue that upfront taxes, such as registration taxes, are the most effective instruments because they counterbalance consumer myopia in evaluating future costs. Consumers are more responsive to upfront taxes as purchasing decisions are more sensitive to upfront prices and taxes than to the expected lifetime costs of the car (Allcott and Wozny (2012), Brand et al. (2013), Kågeson (2005), ICCT (2014), Greene et al. (2005)). However, registration taxes affect only new vehicles sales, whereas fuel and circulation taxes impact both new and used vehicles. Fuel taxes are effective as they act on two dimensions, discouraging the intensity of transport activities and encouraging the shift to more fuel efficient vehicles (Goodwin et al. (2004), Sterner (2007)). While there is disagreement about which policy is ultimately most effective, there is agreement that CO_2-differentiated vehicles taxation can produce large reductions in emissions (COWI (2002)). Moreover, CO_2-differentiated tax and feedbate are more politically acceptable because of potential revenue neutrality, while an increase in fuel taxes is politically unpopular (Greene et al. (2005)).

Many studies on the effects of environmental policies are done ex-ante and are mostly based on simulations (BenDor and Ford (2006), Giblin and McNabola (2009), Greene et al. (2005) and Skippon et al. (2012)). The present work belongs to a growing literature on ex-post evaluation of CO_2-differentiated taxes which have been introduced in Europe in the years around 2007. Various studies have shown that differentiating vehicle taxes on CO_2 emissions is an effective measure to reduce CO_2 intensity, though the magnitude of the results differs across countries and across instruments used. In 2008, France reformed its vehicle registration tax introducing a feebate system.[8] As a consequence, an average decrease of 5% in CO_2 emissions is estimated in the short run, but the generosity of the subsidy increased the sales of new cars by 13% and cost 285 million euro to the state budget. Hence, D'Haultfoeuille et al. (2014) conclude that the environmental short-run impact of the feebate is negative. CO_2-differentiated circulation taxes introduced in Germany and Sweden deliver less clear effects on the average CO_2 intensity of new vehicles compared with the French feebate, confirming that consumers are generally more responsive to upfront taxes (Klier and Linn, 2012). Michielsen et al. (2015) consider 15 European countries and find that a one percent increase in the CO_2 sensitivity of registration taxes reduces the CO_2 intensity of the new fleet by 0.06-0.13 percent. The most relevant point of comparison for Norway is perhaps Ireland. Neither country has a car manufacturing industry, so their policies focus mainly on the demand side of the market. Like Norway, Ireland has substituted the engine size component of its vehicle registration tax with CO_2 performance. Ireland has gone a step further by also differentiating the circulation tax with respect to CO_2 emissions. Results from Rogan et al. (2011) are in line with the present work. In particular, they find a larger short term effect of about 13% reduction of CO_2 intensity, brought about primarily by the shift to diesel-powered vehicles.

The paper is organized as follows: background information specific to Norway is presented in the next section followed by a descriptive analysis of the Norwegian tax system for vehicles and the reform of the VRT in 2007. The data are presented in Section 3, where the main variables of interest are described. Section 4 explain in detail the empirical approach and the identification strategy for the outcome variables of interest. Section 5 presents the main results on primary and secondary variables (5.2). Subsection 5.3 shows the development of CO_2 and NO_x emissions for all passenger cars in Norway. Finally, the discussion (6) and conclusions are provided at the end of the paper.

2 Institutional Background

The strict correlation between GDP and demand for private vehicles is generally well known, and Norway is no exception (Figure D.1 in appendix). Predictably, as the stock of private cars and mileage driven has increased, so have GHG emissions. Emissions of CO_2, the main greenhouse gas, from Norwegian road transport are reaching levels almost 30% higher than those of 1990, making road transport one of the fastest growing sources of CO_2

[8] The feebate system consists in a subsidy for low-emitting vehicles and in a fee for cars emitting more than 160 g of CO_2/km.

emissions in the country.[9] However, Norway has taken preventive actions and thanks to the introduction of more energy-efficient vehicles as well as the blending of hybrids and electric cars, it is well in line with the goal of reducing CO_2 emissions intensity by 40% by 2020.[10] See Figure D.2 in the appendix for a graphical comparison of the CO_2 emission intensity trend for new vehicles in Norway and other European countries.

2.1 Vehicle Registration Tax

Purchase, ownership, and usage taxes serve as economic incentives to affect car purchase and usage decisions. In Norway, these policies are implemented through four elements. The registration tax (1) for new vehicles is a one-time fee paid at the moment of purchase and it accounts for almost half of the retail price. Ownership taxes for passenger cars consist of a flat annual circulation fee (2), and a reclassification fee (3), which applies only to used vehicles.[11] Fuel taxes (4) are determined by various factors including the CO_2 content of the fuel. Historically, the first three elements were primarily levied for state revenue, while fuel taxes reflect road use, accidents and other environmental costs.

This paper focuses on the vehicle registration tax (1). Since 1996, the registration tax has been proportionally linked to three characteristic of a vehicle: its weigh; its engine size; and its power. In 2007, the component of the tax calculated according to engine displacement was substituted with the vehicle's potential CO_2 emissions intensity. In other words, beginning in January 2007, the registration tax on private vehicles became a stepwise function of weight (kg), power (kW), and CO_2 intensity (gCO_2/km).

In order to understand the implications of the 2007 reform, it is important to assess the interdependence among the components of the tax, and how each component affects the monetary value of the registration tax. Engine size, power, and weight are all positively correlated with CO_2 emissions and respectively with each other (Table 1). Hence, by directly calculating the tax over CO_2 intensity as well as over weight and power, the total vehicle registration tax became more sensitive to CO_2 emissions than it was before the reform in 2007. The increase of CO_2 sensitivity is depicted in Figure 2, which highlights the relationship between the total registration tax in 2006 and in 2007 and the CO_2 intensity with linear fitted values differentiated by fuel. For levels between 200 and 300 gCO_2/km the registration tax is higher

[9] Statistic Norway www.ssb.no (SSB: Statistisk Sentralbyrå)

[10] The reduction is compared with the level of 2007. Regulation (EC) No 443/2009 and No 333/2014 of the European Parliament.

[11] The ownership tax was differentiated by fuel type (gasoline or diesel) after 2008, hence it does not affect the present analysis.

in 2007 than it was in 2006. Moreover, the difference in tax between diesel and gasoline is reduced.

Table 1: **Pearson correlation matrix**

	CO_2 int	Weight	Engine	Power	Diesel
CO_2 int	1				
Weight	0.6094	1			
Engine	0.6427	0.8312	1		
Power	0.6845	0.7378	0.8552	1	
Diesel	-0.1804	0.5188	0.3737	0.1558	1

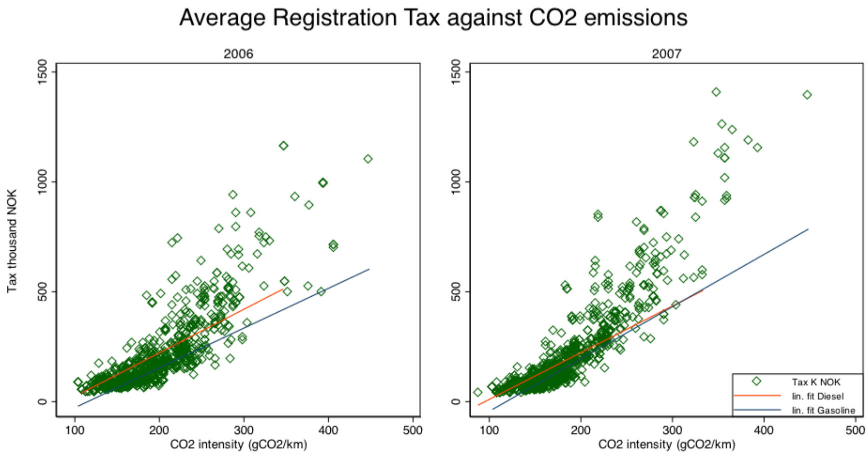

Figure 2: Scatter plot of average registration tax against CO_2 emissions intensity in 2006 and 2007. The two panels show the increase in CO_2 sensitivity of the registration tax before and after the reform. Linear fitted values for diesel and gasoline-fuelled vehicles show that the gap in tax between gasoline and diesel cars is reduced.

It is also possible to evaluate the change in tax paid before and after the reform of 2007 by clustering vehicles according to market segment. The first column of Table 2 illustrates the mean and standard deviation of the registration tax by market segments in 2006 together, with the most sold make and model. The second column shows the difference in tax in between 2006 and 2007. For mini, small, and compact cars, which are associated with lower emissions, weight, and power, the tax in 2007 was about 15% lower than in 2006. For example, buying a mini car, such as the Toyota Aygo, cost about 8 150 NOK, or 15 percent less in 2007 than in 2006. In contrast, consumers spent an average of 20% more to register larger cars, SUVs, or MPV. The registration fee for an SUV like the Suzuki Vitara increased on average by 25 500 NOK in 2007. More details and discussion regarding the registration tax is reported in the Appendix A.

Table 2: Average Change in VRT by Market Segment

Segment	Tax '06	Change '07
Mini (Toyota Aygo)	51.89	-8.15
	(3.47)	(4.20)
Small (Toyota Yaris)	69.35	-11.35
	(9.81)	(7.42)
Compact (Toyota Corolla)	103.77	-11.15
	(27.30)	(26.75)
Medium (VW Passat)	141.81	-4.82
	(37.73)	(23.07)
SUV (Suzuki Vitara)	216.17	+69.59
	(106.75)	(85.10)
MPV (Ford S-Max)	191.96	+25.52
	(68.71)	(32.45)
Large (Volvo V70)	241.58	+35.78
	(70.20)	(85.30)

Thousand NOK (2012 currency). Standard Deviation in parenthesis. The make and model of the most-sold vehicle for each market segment is indicated in parenthesis.

3 Data

The main data used in this study were provided by the Norwegian Road Federation OFVAS[12] and contain detailed information about 670 000 new passenger cars sold in Norway between 2004 and 2009. These data are repeated cross section, with monthly registrations by vehicle specification in each municipality of Norway, i.e. panel data at month and municipality level.[13] Vehicle specifications are defined by brand, model, weight, engine displacement, power, potential CO_2 emissions, fuel type, number of doors, and transmission type. Vehicle-specific taxes have been calculated on the basis of these characteristics following the scheme provided by OFVAS.

Other information regarding population, yearly gross income per capita for Norwegian municipalities, and average fleet age at the county level was provided by Statistic Norway (SSB).[14] Monthly average fuel prices and fuel taxes for both gasoline and diesel in Norway were provided by the Institute of Transport Economics (TØI).[15] Summary statistics for the most relevant vehicle characteristics are reported in Table 3.

[12] Opplysningsrådet for Veitrafikken AS (OFV AS) http://ofvas.no/

[13] Norway counts 428 municipalities (kommuner) in 2013.

[14] Statistisk Sentralbyrå, www.ssb.no.

[15] www.toi.no

Table 3: Most sold model, total number of new vehicles registered each year and mean of the main vehicles' characteristics.

Year	Top sold model	Tot cars sold	CO_2 int. (g/km)	Weight (Kg)	Power (kW)	Diesel Share
2004	Toyota Av.	115 600	180.44	1332.76	85.29	28%
2005	Toyota Cor.	109 846	175.62	1349.55	85.23	39%
2006	VW Passat	109 098	177.32	1402.94	89.92	48%
2007	VW Passat	129 121	159.40	1403.05	86.97	74%
2008	VW Golf	110 540	158.99	1418.45	89.78	73%
2009	VW Golf	98 640	151.35	1413.07	89.6	73%

Source: www.ofvas.no

3.1 Main variables

This study identifies the effects of 2007 reform of the registration tax on three main outcome variables: CO_2 emissions intensity, the share of high CO_2-emitting cars, and the market share of diesel cars. The choice of outcome variables is somehow limited by data availability for the observation period of interest. In particular, additional types of pollutant such as PM and NO_x levels would have made this analysis and discussion of the effect of the reform more complete, see Bollen and Brink (2014) for a discussion. This issue is further discussed in the discussed section.

The following descriptive analysis reveals several important changes in the characteristics of the passenger vehicle fleet in Norway between 2004 and 2009. The overall decline of the trend illustrated in Figure 1 is due in part to improvements in fuel efficiency of the vehicles available on the market and in part to a shift on the demand side. In this paper, the demand-side is taken as main focus of the analysis. Demand responses by Norwegian consumers include a shift toward less CO_2 intensive cars and toward diesel-fueled, rather than gasoline-fueled, vehicles. The next sections describe in more details each of the three main outcome variables of interest.

CO_2 emissions intensity

The average CO_2 intensity of the new car fleet decreased by almost 30 gCO_2/km: from an average of 180 in 2004 to about 151 gCO_2/km in 2009 (Figure 1 and Table 3). In October 2006, the Norwegian Ministry of Finance presented a proposal for the 2007 national budget which included the suggested change to the vehicle registration tax system.[16] Public discus-

[16] Stortingsproposisjon nummer 1 (2006-2007) http://www.statsbudsjettet.no/Statsbudsjettet-2007/

sion of the proposed changes led to a high level of anticipation behavior in November and December 2006. This announcement effect is identifiable in Figure 1, where the drastic increase in average CO_2 intensity in November and December 2006 is followed by a drop in CO_2 intensity beginning in January 2007 when the reform was activated. The density of the average CO_2 intensity shifted toward lower emissions in 2007 compared with 2006 (Figure 3). Most of the distribution became concentrated below the 180gCO_2/km cutoff. Figure 3 also shows some threshold effects. Specifically, there is a reduction right after the 140 and the 180 cut off which was absent in 2006.

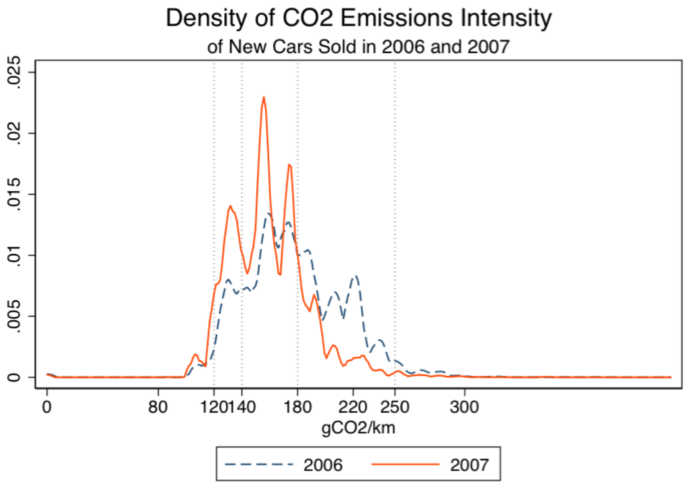

Figure 3: Density of CO_2 emissions intensity in the years before and after the reform. Vehicles with zero emissions are electric, gas, hybrid and hydrogen cars which account for about 2% of the sample.

Low- versus high-CO2 intensity vehicle shares

Examining the purchases of different classes of vehicles is another way to understand what happened in the months immediately before and after the 2007 reform. Figure 4 shows the market share of new cars purchased by the CO_2 thresholds used in the calculation of the registration tax. It appears that the discontinuity observed in the CO_2 intensity trend is an inter-temporal substitution between high- and low-CO2 emitting cars. This substitution is clearly visible in Figure 4, where opposite trends are depicted for different kinds of vehicles in the two panels. Sales of vehicles with low CO_2 intensity in the left panel, i.e. those emitting less than 180 gCO_2/km decrease before January 2007 and increase immediately after. Vehicles with high CO_2 intensity reported in the right panel show the opposite trend[17]. Figure 5 plots only the share of highly-emitting cars, which is the second outcome variable considered in this study. The share of cars emitting more than 180 gCO_2/km decreased by almost 30 percentage points, from an average of 43% in 2004 to about 16% in 2009.

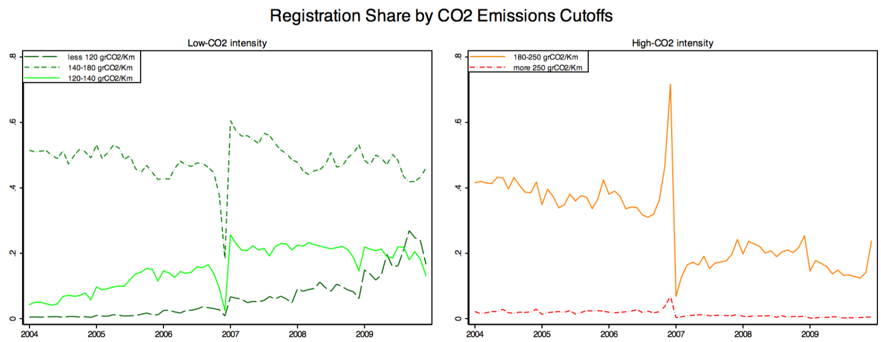

Figure 4: Share of new vehicles registered by CO_2 intensity category. The categories are made by taking into account how the CO_2 component of the tax is structured. Note that the two panels show market shares so they sum to one.

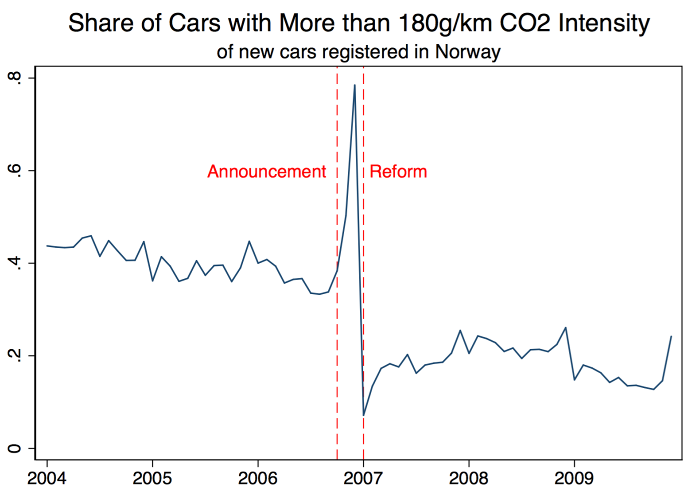

Figure 5: Market share of new registered vehicles with more than 180 g per km of CO_2 intensity.

[17]The choice of 180 as division between "low" and "high" CO2 emitting cars comes from the exogenous thresholds imposed by the tax and the observed behaviour of vehicles shares.

Diesel-powered vehicles

The market share of diesel cars increased greatly between 2004 and 2009 (Figure 6). From levels around 28% in 2004, diesel-powered vehicles reached levels around 73% in 2009 (Table 3). The increasing trend can be partially explained by specific taste for the superior fuel efficiency of diesel engines and the relatively lower price of fuel. In Norway, fuel prices are lower for diesel than for gasoline (Figure D.3), but vehicle taxes favor gasoline cars (Figure 7).

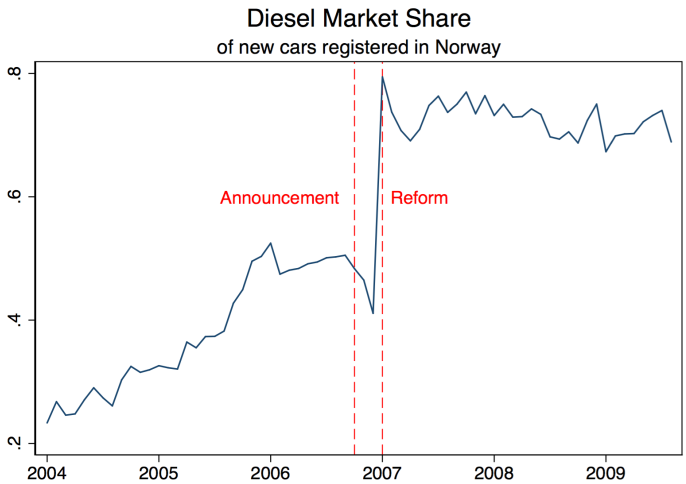

Figure 6: Diesel share from January 2004 until December 2009

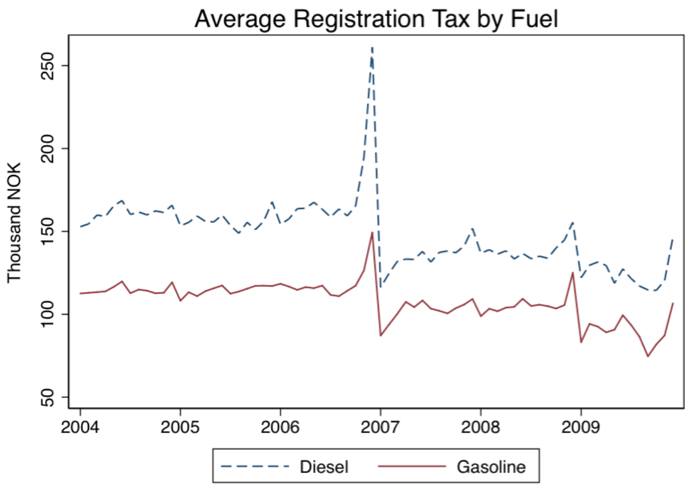

Figure 7: Average vehicle registration tax by fuel type. Diesel vehicles pay a higher registration tax than gasoline cars. However, after the 2007 reform the price gap is reduced.

To assess the effect of the reform on the tax it is useful to separate vehicles characteristics by fuel type. Diesel cars have, on average, larger engine size, higher weight, and higher power, but lower CO_2 intensity than their gasoline equivalents (Figure 8).

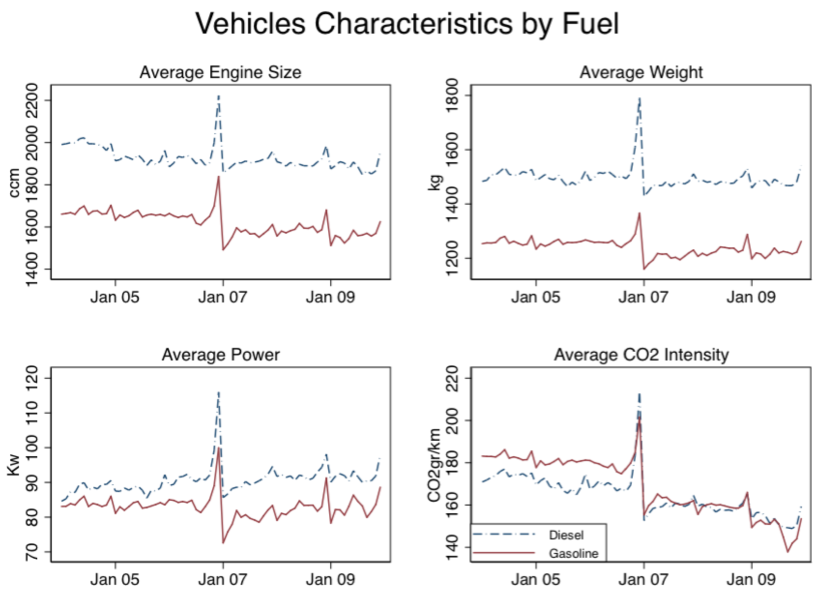

Figure 8: Average engine size, weight, power, and CO_2 intensity of new registered vehicles by fuel type.

This meant that when the registration tax was calculated based on the engine size, diesel-fuelled vehicles were more expensive than gasoline cars with similar characteristics. Because of the substitution of the engine size component with the CO_2 emissions intensity, diesel cars became relatively cheaper and hence their demand is expected to increase. Specifically, the difference in registration tax for diesel and gasoline cars decreased from an average of 56 000 NOK in 2006 to an average of 32 000 NOK in 2007.

This paper argues that a large part of the observed increase in the market share of diesel cars was the result of the registration tax reform of 2007 and this pattern is consistent with other studies such as Michielsen et al. (2015) and Rogan et al. (2011). More implication of this increase is discussed in the discussion section 6.

4 Empirical Approach and Identification.

What is the impact of differentiating the vehicle registration tax on CO_2 emissions intensity? To answer this question, a Difference in Differences (DID) approach is used and the reform of 2007 is exploited to estimate the causal environmental effects, in the short run. Specifically the estimation of the impact of the reform is carried out on three outcome variables: average CO_2 emissions intensity, the share of high CO_2-intensive cars, and the share of diesel vehicles. This section assesses how much of the change observed in these variables is associated with the tax reform of 2007.

By using the DID estimator it is possible to calculate the causal effect net of time trends and market seasonality, and control for exogenous factors that are potentially relevant for the outcome variables. For instance, the average CO_2 intensity of vehicles purchased in the nine months before the reform is about 12.6 g of CO_2 per kilometer higher than the average for those bought after the reform. Considering only this simple difference, however, produces a biased estimation of the real change in the average CO_2 intensity of the new fleet as long as the time trend is non-zero. As discussed previously, the reduction in CO_2 intensity is in fact due to both a supply and a demand effect.

The DID method is used to evaluate the impact of a treatment on an outcome variable over a population. Generally, the population is divided in two groups: those who receive the treatment (the treated), and those who do not (the control group). This allows for a direct comparison, under specific assumptions, between the control and the treatment group. In this paper, the tax reform was applied to all vehicles in the market at the same time in Norway. Hence, there is no optimal control group in the standard sense. When dealing with cross sectional data, however, it is possible to compensate for the lack of control group by employing previous observations in time, when comparable to the primary observations of interest. Similar strategies have been used by Schönberg and Ludsteck (2012), Lalive and Zweimüller (2009), Lalive et al. (2010) and Ekberg et al. (2013).

In order to isolate the causal impact of the reform, observation of the outcome variables in previous years, when no reform took place, are used as a control. Specifically, two nine-month periods in 2006 and 2007 are used as the treatment observations, one nine-months period before the intervention and one period after. Two corresponding nine-month periods in 2004 and 2005 are used as control observations. A visual comparison of treatment and control is presented in Appendix B.

As indicated in the previous section, the registration tax reform was announced in October 2006. From Figure 1 it is clear that the announcement of the reform led to a high level of anticipation behavior where CO_2 intensive vehicles experienced an extraordinary increase in their purchase before January 2007. Threats to identification can arise when individuals change their behavior as a consequence of the treatment, or in anticipation of it. Therefore, the months between October 2006 and March 2007 are excluded from the analysis. Appendix C reports robustness checks where the after-treatment period is postponed to check whether the adjustment period was longer than three months.

Following a standard DID procedure, Equation (1) is estimated for three outcome variables ($Y_{r,t}$): the average CO_2 emissions intensity, the share of high CO_2 intensive cars, and the share of diesel cars bought. The level of aggregation used to calculate the averages is municipalities $r = 1, 2, ..., R$ and months $t = \{t_1, t_2, t_3, t_4\}$.[18]

$$\bar{Y}_{r,t} = \alpha + \beta Reform_{t_3,t_4} + \gamma After_{t_2,t_4} + \delta After \cdot Reform_{t_4} + \mu C'_{r,t} + \epsilon_{r,t} \quad (1)$$

Where

- t_1 identifies the months between January and September 2004,
- t_2 is equal to one for observations between April and December 2005,
- t_3 identifies the months between January and September 2006, and
- t_4 identifies the months from April to December 2007.

The regressor $Reform_t = 1 \; for \; t = \{t_3, t_4\}$ is a dummy variable indicating which observations belong to the years of the treatment, namely t_3 and t_4. The variable $After_t = 1 \; for \; t = \{t_2, t_4\}$ identifies the periods after

[18] The total number of municipalities included in the analysis is 437 because some municipalities were split and other joint during the years considered in the study. As a consequence the panel is not perfectly balanced.

the treatment in the year of the reform and for the control group. The variable takes the value 1 for the months between April and December 2005 and from April to December 2007 and zero otherwise. $After_t \cdot Reform_t = 1\ for\ t = \{t_4\}$ is the interaction term identifying the nine-month period after the treatment. Lastly, $C'_{r,t}$ is a vector of control variables. $\epsilon_{r,t}$ is a random, unobserved error term.

In order to have an unbiased estimation of the treatment effect δ, some assumptions must be verified. The model needs to be correctly specified and the error term needs to be uncorrelated with the variables in the equation. The identifying assumption is that treatment and control observations differ only because of the treatment. In other words, the Common Trend Assumption (CTA) states that in absence of intervention treatment and control groups would have common trends. This assumption is, in principle, untestable, however, a testable implication is that the pre-intervention trends in the control and treatment should be parallel. This implication is often used to infer the plausibility of the CTA. This study compares the trends for the time periods employed in the estimations in Appendix B.

The similarity in trends, lies in the seasonality of the car market. The comparability between treatment and control observations is reasonable given the regularity in the production cycles for cars. In the European market, one cycle correspond to a calendar year, meaning vehicles characteristics are constant for twelve-month periods. It is enough to attribute the observable trend in the outcome variables as an exogenous factor intrinsic with the supply side, and exploit the same months from the previous year as a feasible control group. To visually verify the seasonal regularity of the car market, the treatment group and control group are compared in Appendix B. If we exclude the months immediately before and after the reform, the trends in the years of interest are analogous. This guarantees that the causal effect of the reform can be identified as the gap between the trends before and after the reform.

Possible threats to identification can arise in presence of exogenous factors affecting the outcome variables differently in different years/months. This study includes relevant time-varing control variables: annual per capita gross income at the municipality level, monthly fuel prices in Norway, and the average fleet age at the county level.

5 Results

5.1 Main Variables

This section presents and discusses the overall findings of the paper. To evaluate the causal impact of the registration tax reform of 2007, the treatment effect is estimated for each outcome variable of interest $Y_{r,t}$ using Equation 1. The averages for the outcome variables are calculated at the municipality level for the 36 months used in the analysis.

The treatment effect δ can also be calculated in a more direct and intuitive way by following the definition of the DID estimator. See, for example, Table 4 which exemplifies this calculation for the outcome variable CO_2 intensity. The DID estimator calculates the difference between the pre- and post-reform averages in the year of the intervention (treatment) minus the difference between the same time intervals in the control.

Table 4: Treatment effect for CO_2 intensity calculated by applying the DID definition.

$\overline{CO_2}$	Post-Reform	Pre-Reform	**Diff**
Treatment	$\overline{Y}_{r,t_4} = 160.57$	$\overline{Y}_{r,t_3} = 173.12$	-12.55
Control	$\overline{Y}_{r,t_2} = 175.38$	$\overline{Y}_{r,t_1} = 180.53$	-5.15
Diff	-14.81	-7.41	-7.4

Comparing the CO_2 intensity averages before and after the reform, we find a reduction of 12.55 g of CO_2 per km. This result cannot be interpreted as a consequence of the intervention. The observed reduction is due to a combination of improvements in fuel efficiency of the vehicles available on the market and a shift in the demand side, which could be a reaction to the 2007 reform of the registration tax. Using the DID approach we learn that the causal impact of tax reform on the demand is about 60% of the overall reduction observed before and after the reform. Specifically, Table 4 reports a reduction of 7.4 gCO_2/km, which corresponds to about a 4.3% of the pre-treatment average. This simple calculation can be compared with the results of the OLS estimation reported in Table 5. The advantage of OSL is the possibility of introducing control variables and the convenience of calculating standard errors.

All models reported in Table 5 are weighted on the number of car sold and have robust standard errors clustered on municipalities to account for possible similarities in demand of different time periods within the same municipality. For each outcome variable of interest, Column (2) includes potentially relevant time-varying control variables: gross income at municipality level, the ratio between diesel and gasoline fuel prices (including fuel taxes), and the average age of the car fleet in the 19 Norwegian counties. All

Table 5: Estimation results

	(1) CO2 int.	(2) CO2 int.	(1) High-poll.	(2) High-poll.	(1) Diesel	(2) Diesel
Treatment eff	-7.398***	-7.608***	-0.124***	-0.116***	0.193***	0.207***
	(0.491)	(0.444)	(0.00662)	(0.00675)	(0.00824)	(0.00786)
Group effect	-7.414***	-7.845***	-0.0731***	-0.0823***	0.175***	0.176***
	(0.314)	(0.318)	(0.00389)	(0.00401)	(0.00598)	(0.00735)
Time effect	-5.153***	-6.198***	-0.0493***	-0.0662***	0.104***	0.111***
	(0.292)	(0.507)	(0.00545)	(0.00795)	(0.00521)	(0.00698)
Income		0.0407***		0.000450***		-0.000527***
		(0.0106)		(0.000118)		(0.000149)
Diesel/Gas price		-2.426		0.121***		0.203***
		(2.540)		(0.0329)		(0.0286)
Fleet age		-0.118		-0.00161		0.0259***
		(0.522)		(0.00644)		(0.00558)
Constant	180.5***	172.0***	0.438***	0.216*	0.0876***	-0.198*
	(0.911)	(6.606)	(0.0107)	(0.0841)	(0.00643)	(0.0963)
Observations	13813	13577	13813	13577	23833	23430
Adjusted R^2	0.497	0.534	0.429	0.455	0.307	0.331

Robust standard errors clustered on municipalities.

the treatment effects are highlighted in the first row of Table 5. They are highly significant and stable when including control variables.

For the outcome variable CO_2 intensity, the model estimates a change between 7.4 and 7.6 gCO_2 per km. The interpretation of these coefficients is that the reform caused a reduction in average CO_2 intensity of about 4.3% from the pre-treatment average within 2007 net of time trends and anticipation effects. This effect is quite large since it accounts for about 20% of the overall standard deviation. The estimated causal impact of the reform corresponds to about 60% of the overall reduction in the CO_2 intensity observed between 2006 and 2007, which includes exogenous factors such as fuel efficiency improvements associate with the supply side of the market.

To understand the mechanism behind the estimated reduction of CO_2 emissions intensity of the car fleet, this study also considers the impact of the tax reform on the share of high CO_2 intensive vehicles relative to medium-low CO_2 intensive vehicles, and on the share of diesel cars. Demand-side responses by the Norwegian consumers include a shift toward low CO_2 emitting vehicles and toward more diesel-fueled cars. Table 5 shows that the reform caused a decrease in the share of highly CO_2 emitting vehicles (more than 180g of CO_2 per km) of about 12 percentage points. Diesel cars, instead, increased their market share between 19 and 21 percentage points in the short run.

Figure 5 shows that the share of cars emitting more than 180 g CO_2/km decreased by almost 30 percentage points, from an average of 43% in 2004 to about 16% in 2009. Hence, the reform of 2007 caused almost half of the observed reduction within the same year.

At the same time we observed a general increase in the share of diesel cars, from levels around 28% in 2004 diesel-powered vehicles reach levels around 73% in 2009 (Figure 6). Part of this increase can be attributed to the substitution of the CO_2 intensity component for the engine size component of the registration tax. Given the higher engine size and the lower CO_2 emissions associated with diesel vehicles, the overall tax makes diesel cars relatively cheaper in 2007 than in 2006 (Figure 7). The remaining part of the trend can be associated with a specific taste for diesel powered vehicles which have, on average, higher fuel economy than gasoline cars and run on a cheaper fuel (Figure D.3).

5.2 Secondary Variables

This section reports the impact of the 2007 reform on other characteristics of the vehicles. It is plausible to expect some change in other characteristics such as weight, power, and engine size. Moreover, given the increase of the share of diesel-fuelled cars, it is important to consider whether these vehicles have characteristics that differentiate them from the average fleet. As Figure 8 shows, the engine size, weight, and power of diesel cars are higher than those of gasoline cars. Figure 9, 10, and 11 show the trends for weight, power, and engine size. There seems to be a small increase for weight and power, but it is not clear whether the reform created any effect in the short run.

Table 6 reports the estimations for the outcome variables weight, power, and engine size. There is no significant increase in weight and a low significant increase for power. In contrast, the average engine size increased significantly in the short run. The estimated effect is about 47 ccm more in 2007. This effect correspond to a 2.6% increase from pre-treatment averages. However, from Figure 11 we notice a decrease in the trend after 2008, so even if the reform has created a short run effect, this effect disappears in the longer run.

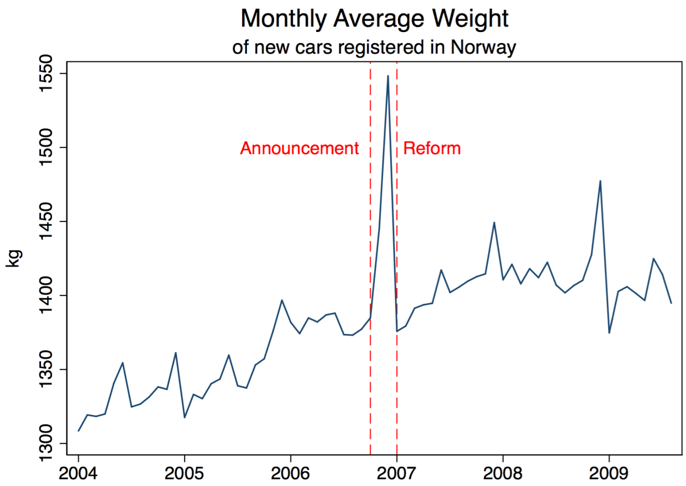

Figure 9: The average weight of new registered vehicles increases until 2008 and then stabilises afterward.

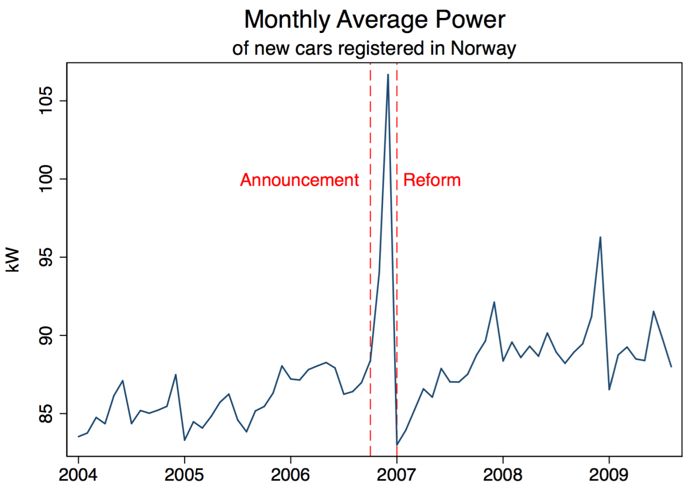

Figure 10: The average power of new registered vehicles increases slightly with time.

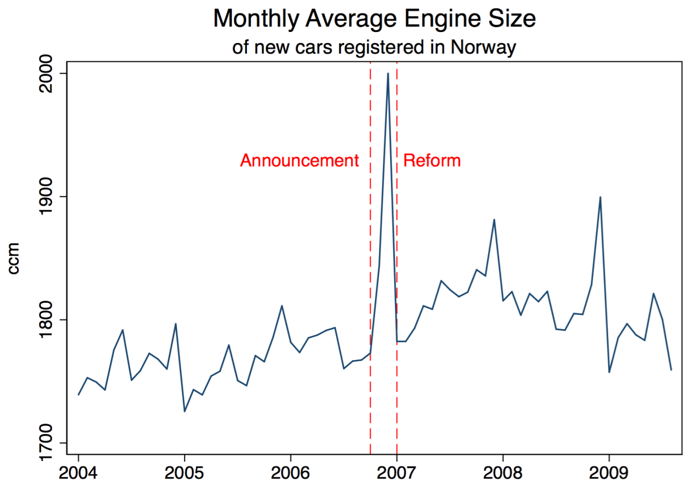

Figure 11: The average engine size of new registered vehicles increases slightly until 2008 and then decreases.

Lastly, it is also important to wonder whether the reform has induced an increase or decrease in the total number of cars sold. Figure D.1 shows how the total number of sales are correlated with GDP per capita. The first column of Table 6 reports the estimated effect of the reform on the total number of registrations. The coefficient is non-significant, hence we cannot attribute any change in the number of cars sold to the implementation of the reform.

Table 6: Estimation results of additional variables

	Weight	Power	Engine size	Registrations
Treatment eff	6.064	0.569*	46.71***	-1.229
	(3.789)	(0.282)	(4.291)	(1.552)
Group effect	48.94***	1.744***	13.30***	-15.35***
	(2.500)	(0.220)	(3.804)	(4.576)
Time effect	20.94***	-0.569	-1.979	-17.66***
	(4.370)	(0.448)	(6.012)	(5.082)
Gross Income	0.191*	0.0332**	0.324*	0.862***
	(0.0933)	(0.0114)	(0.159)	(0.257)
Diesel/Gas price	74.56***	9.708***	88.70*	-22.73***
	(21.00)	(2.345)	(35.57)	(4.419)
Fleet age	7.439	0.0757	8.936	-3.104
	(4.657)	(0.550)	(8.045)	(4.883)
Constant	1131.0***	65.94***	1496.8***	-136.9
	(57.42)	(6.870)	(106.9)	(71.25)
Observations	13577	13577	13577	13577
Adjusted R^2	0.251	0.124	0.111	0.150

Robust standard errors clustered on municipalities.

5.3 Emissions from all passenger cars

The main results section 5 has shown that reforming the tax system for newly purchased cars in Norway had an important impact on the average CO_2 emissions intensity as well as on other variables. While the average CO_2 intensity was reduced by about 7gr/Km in the short run, the number of diesel cars sold in Norway increased with its share reaching 73% by the end of 2009. Diesel cars are generally associated with lower emission of CO_2 compared to their gasoline counterpart, but they emit other harmful pollutants, such as nitrogen oxides (NO_x). Further discussion of this issue is developed in the discussion section 6. The current section presents the overall trend of CO_2 and NO_x emissions generated from all passenger cars in Norway.

Annual data on CO_2 and NO_x emissions for all passenger cars in Norway are shown in Figure 12 and Table 7 broken down by vehicles' fuel type. These data are reported by the Norwegian institute of statistic: Statistic Norway (SSB), and are based on a bottom-up model that includes all passengers vehicles on the Norwegian territory [19]. While this paper has so far focused only on new purchased vehicles, it is interesting to compare the results with the development of emissions deriving from all cars driven on the Norwegian roads over the years.

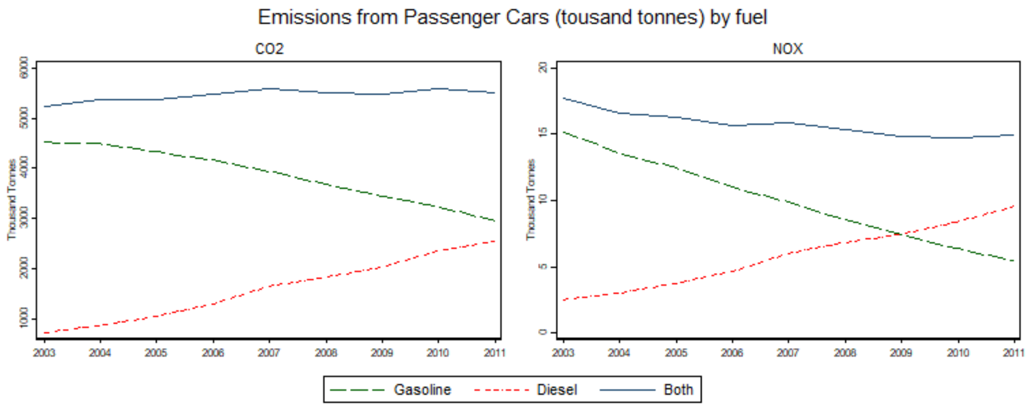

Figure 12: CO_2 and NO_x emissions for all passenger cars in Norway by fuel (thousand tonnes). Source: Statistic Norway (SSB).

[19] Total emissions of CO_2 are estimated from the carbon content of purchased fuels (gasoline and diesel), while NO_x are calculated based on estimated mileage. See the Handbook of Emission Factors (HBEFA) (INFRAS 2014) and the Ministry of Climate and Environment website NIR for more details http://www.miljodirektoratet.no/no/Publikasjoner/2017/April-2017/Greenhouse-Gas-Emissions-1990-2015-National-Inventory-Report/.

The left panel of Figure 12 shows an overall increase in the total CO_2 emissions over the years between 2003 and 2011. This trend is further disaggregated between gasoline and diesel-fueled vehicles. The two trends go in opposite directions: while the total CO_2 produced by gasoline cars is reduced over time, the amount of the same gas produced by diesel vehicles rises. Similarly for NO_x emissions, we observe the trends of gasoline and diesel-fueled vehicles going in opposite directions: the first declining and the second rising (right panel of Figure 12). In contrast with CO_2 emissions, the total amount of NO_x emissions slightly decreases over time.

Table 7: Total CO_2 and NO_x Emissions (thousand tonnes)

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
CO_2									
Gasoline	4518	4492	4328	4167	3942	3685	3450	3242	2949
Diesel	721	872	1046	1303	1647	1829	2029	2355	2552
Total	5239	5364	5374	5470	5589	5514	5479	5597	5501
NO_x									
Gasoline	15.18	13.59	12.50	11.01	9.880	8.549	7.408	6.362	5.432
Diesel	2.512	3.010	3.754	4.614	6.011	6.828	7.474	8.406	9.562
Total	17.69	16.60	16.25	15.62	15.89	15.38	14.88	14.77	14.99

Source: Statistic Norway (SSB)

It is interesting to compare these figures with the main part of the paper, for example with Figure 1. The total amount of CO_2 is still increasing in spite of the estimated reduction in the average CO_2 emission intensity for new registered vehicles caused by the reform. Moreover, Figure 12 highlights the importance of diesel vehicles also for the development of CO_2 emissions. Total CO_2 emissions deriving from diesel vehicles quadrupled, going from 721 thousand tonnes of 2003 to 2552 in 2011. While the CO_2 (thousand) tonnes emitted by gasoline-fueled vehicles decreased going from 4518 (2003) to 2949 (2011).

Focusing on NO_x emissions, we observe a similar pattern. The amount of NO_x emitted by gasoline cars goes from about 15 thousand tonnes in 2003 to 5.4 in 2011. In contrast, diesel cars emitted almost four times as much NO_x going from 2.5 thousand tonnes in 2003 to 9.6 in 2011. Even though a causal effect is not estimated, it is clear that the increase of diesel market share among the new vehicles (Figure 6) must have contributed to the observed increase of NO_x emissions, at least to some extent.

It light of such findings it is also important to consider that according to a report from the Norwegian Environment Agency (2017), "vehicle kilometers have increased by 46.6 per cent and the number of passenger cars has grown by 58 per cent" in 2015 relative to 1990 levels (p. 105). Hence, that the reduction in CO_2 emissions is offset by the increasing number of vehicles in the street and the number of km driven (see also Fig. D.4, source SSB.).

The main focus of the current article is to estimate the effect of the 2007 tax reform on the market for new vehicles in Norway. This section has presented and discussed the overall trend for both CO_2 and NO_x emissions in Norway in order to provide a more complete picture. Nevertheless, comparison of different data sources is extremely difficult especially in light of the discrepancy between theoretical-laboratory measurement and emissions in real traffic, as discussed in Tietge et al. (2015). More research is needed on this topic. For instance, future work could be dedicated to properly estimate the causal effect of the 2007 reform on NO_x emissions and of the other reforms that were introduced in Norway after that.

6 Discussion

This paper focuses on the estimation of the causal effect of the 2007 tax reform in Norway. This reform substituted the engine size component of the vehicle registration tax with a CO_2 emissions intensity component, to discourage the purchase of new vehicles with high potential emissions of CO_2. These sorts of reforms have been quite popular in the last decade in different European countries following EU regulations which mandated the reduction of CO_2 emissions. This study shows that this reform succeeded in reducing the average CO_2 emission intensity of the fleet of new cars, but that its narrow focus created an important side effect: the increase of diesel market shares.

By focusing only on CO_2 emissions, the tax indirectly stimulated the purchase of diesel vehicles because they emit less CO_2 than their gasoline counterpart. Even though diesels emit less CO_2 emissions, they are not "greener" as they emit other harmful pollutants much more than gasoline cars, such as nitrogen oxides (NO_x). Unlike CO_2 that accumulate in the atmosphere, they remain at a local level. Hence, while they are not considered harmful to the global environment, they are greatly affecting people's health (Lelieveld et al., 2015).

This issue has been widely discussed in recent years. On the one hand, some have argued that increasing the share of diesel-powered vehicles is an efficient transition strategy toward a more sustainable transportation system with lower CO_2 emissions (Zervas, 2006). On the other hand, Mayeres and Proost (2001) find that diesel cars have higher social costs than those of gasoline cars and that by increasing the taxation of diesel it is possible to achieve welfare improvements. The media have also focused a lot on the issue. For instance, the Guardian stated that "the European commission was lobbied strongly by big German car makers BMW, Volkswagen and Daimler, to incentivise diesel. A switch to diesel was said by the industry to be a cheap and fast way to reduce the carbon emissions that drive climate change" and that the EC 1998 Acea agreement[20] "was practically an order to switch to diesel" cars (Vidal, 2015). As a result, the market share of diesel cars has dramatically increased in many European countries (see for instance: Klier and Linn (2012), Michielsen et al. (2015) and Rogan et al. (2011)).

This increase of diesel market shares and its possible adverse effect have not gone unnoticed for long, at least in Norway. In 2013, the Norwegian government further reformed the registration tax and included a component specific for NO_x in order to limit the problem. To further understand the implication of the reform one would ideally use the same approach to estimate the increase in NO_x emissions. Unfortunately, such formal analysis cannot not be carried out at present for lack of relevant data in the period of interest.

Nevertheless, chapter 5.3 assess the overall development of both CO_2 and NO_x emissions for all cars in Norway - new and used ones. The results indicate that the increase in diesel shares are associated with an increase in both NO_x and CO_2 emissions. Overall, we observe an increase in CO_2 emissions, which is probably the result of the continuous increase in the number of cars in the Norwegian fleet, and a slight decrease in NO_x. But to what extent we would have had a more important fall of NO_x emissions without the increase of diesels market shares remain an open question. A proper analysis of such effect and the impact of subsequent reforms, for instance the one of 2013 is left for future work.

7 Conclusions

This paper analyses how a recent policy intervention has affected the main characteristics of the new car fleet in Norway. In 2007, the structure of the vehicle registration tax changed. Taxation for new passenger cars became based on expected CO_2 emissions per kilometer rather than engine size. This reform was implemented with the goal of reducing the average CO_2 emissions intensity of the fleet. Using observational data on car purchases provided by the Norwegian Road Federation OFVAS, the short run effect of the 2007 reform is estimated on three dimensions: 1) the average CO_2 intensity of new registered vehicles, 2) the relative change between low and high CO_2 intensive cars in the market and 3) the market share of diesel cars.

[20] http://europa.eu/rapid/press-release_IP-98-734_en.htm?locale=en

The change in the tax structure did indeed result in an important reduction of the average CO_2 intensity. The estimated treatment effect is about 7.5 g of CO_2 per km less then we would have had without the reform. This reduction accounts for about half of the overall reduction in CO_2 intensity when including exogenous fuel efficiency improvements associated with the supply side of the market. The observed improvement in CO_2 performance is the result of a shift in demand toward greener vehicles. In particular, within the year of the policy implementation, the share of high CO_2 intensity vehicles dropped by about 12 percentage points and the market share of diesel cars has increased by about 20 percentage points.

This study also investigates whether the implementation of the reform has affected other characteristics such as weight, power, and engine size of the new purchased vehicles and whether it affected the total number of registrations. The main result here is that the reform did not provoke an absolute increase in the number of car purchased.

Finally, the CO_2 and NO_x emissions for all passenger cars in Norway are assessed and two main results are drawn. The total amount of CO_2 is still increasing, while the amount of NO_x is slowly decreasing despite the large increase of new diesel vehicles on the street.

Appendix

A Vehicle Registration tax

Table A.1 shows the tax bands for each element used to calculate the registration tax for the years considered in this analysis. Before 2007, the VRT was calculated using three characteristic of a vehicle: its weigh (km); its engine displacement (cylinder capacity cm3); and its power (kW). From January 2007, it was calculated based on the weight (kg), power (kW), and CO_2 intensity (g/km) of the purchased vehicle.

Table A.1: **Bands for the VRT components in different years**

		2004	**2005**	**2006**	**2007**	**2008**
Weight (kg)	0-1150	39.52	39.76	39.16	36.82	36.40
	1151-1400	79.04	79.52	79.45	80.25	79.32
	1401-1500	158.10	159.05	157.77	160.52	158.67
	over 1500	183.87	184.97	183.51	186.68	184.53
Power (kW)	0-65	152.66	153.58	153.30	133.91	132.37
	66-90	556.79	560.14	557.24	557.97	551.55
	91-130	1113.93	1120.63	1115.59	1339.12	1323.71
	over 130	1885.04	1896.37	1886.54	2789.83	2757.73
Engine Vol (ccm)	0-1200	11.67	11.74	11.68		
	1201-1800	30.55	30.73	30.58		
	1801-2200	71.86	72.29	71.94		
	over 2200	89.77	90.31	90.42		
gCO_2/km	0-120				44.64	44.13
	121-140				212.03	209.59
	141-180				557.97	551.55
	181-250				1562.30	1544.54
	over 250				1562.30	1544.54

Prices are in NOK (2012 currency)

Before 2007, the weight component accounted on average for 54% of the overall registration tax, while the power and engine size components accounted for 19% and 27% respectively. After the intervention, the new CO_2 intensity component accounted for about 18% of the total tax, while the power component remained quite stable around 20%. As a consequence, the vehicle's weight became more important and accounts for about 60% of the overall registration tax (Figure A.1).

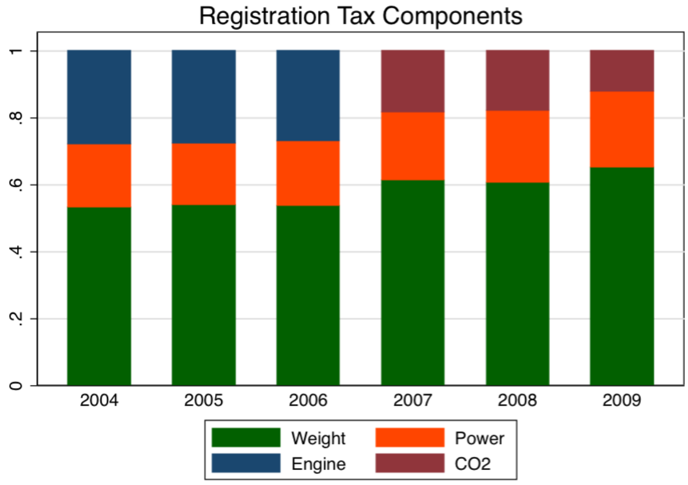

Figure A.1: Vehicle registration tax components and their weights over the years.

By plotting each component of the registration tax against the total value of the VRT expressed in thousand NOK, it is possible to understand how the tax has changed over time, and in particular, how the total value of the tax changed after the reform in 2007. The marginal tax rate for the weight component is almost unchanged through the years, while the marginal rate based on the car's power increased in 2007, making vehicles with engine power higher than 130 kW more expensive (Figure A.2).

Comparing the CO_2 intensity component introduced in 2007 with the engine size component of 2006, it is clear that the tax calculated over the CO_2 emissions factor is steeper (Figure A.3). As a consequence, the monetary value of registration tax became higher for high CO_2 intensive vehicles compared to tax values registered in 2006.

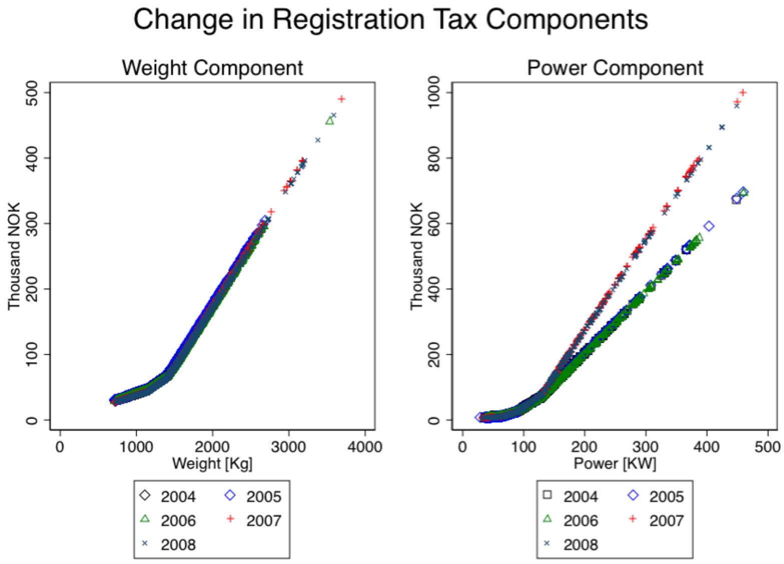

Figure A.2: Scatter plot for the weight and power components of the registration tax for different years. The weight component remained almost constant, while the power component of the registration tax increased in 2007.

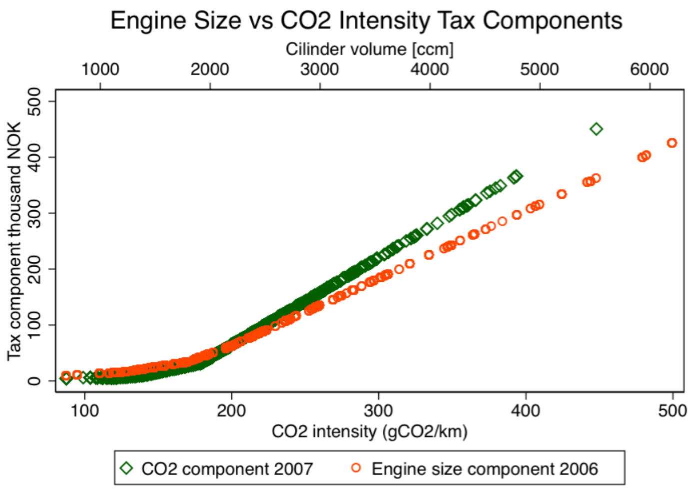

Figure A.3: With the reform of 2007 the CO_2 intensity component of the registration tax substituted the engine component. The round scatter plot represents the amount in thousand NOK of the tax component calculated over the engine size in 2006. The diamond scatter plot represents the amount of tax paid for CO_2 intensity.

B Comparison between control and treatment group

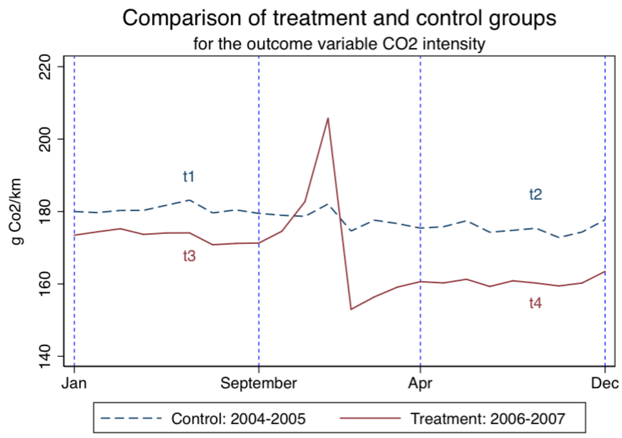

Figure B.1: Comparison of treatment and control groups for the variable CO_2 intensity $Control = t_1, t_2$ and $Treatment = t_3, t_4$, where t_1 is April-December 2004, t_2 is January-September 2005, t_3 is January-September 2006 and t_4 is April-December 2007.

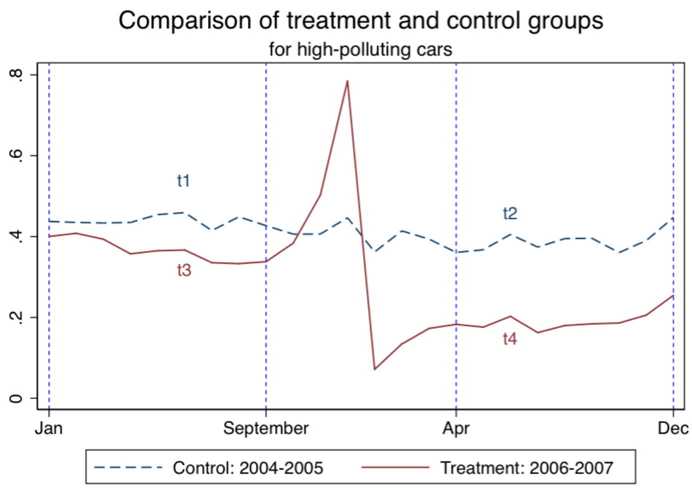

Figure B.2: Comparison of treatment and control groups for cars emitting more than $180 gCO_2/km$. $Control = t_1, t_2$ and $Treatment = t_3, t_4$, where t_1 is April-December 2004, t_2 is January-September 2005, t_3 is January-September 2006 and t_4 is April-December 2007.

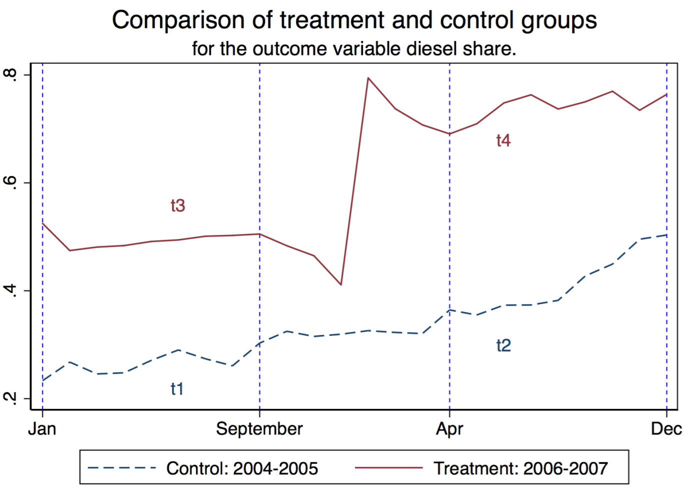

Figure B.3: Comparison of treatment and control groups for diesel share. $Control = t_1, t_2$ and $Treatment = t_3, t_4$, where t_1 is April-December 2004, t_2 is January-September 2005, t_3 is January-September 2006 and t_4 is April-December 2007.

C Robustness check

To ensure the robustness of the estimation results presented in this work, the estimation for all outcome variables is carried out by postponing the after-treatment period. In the original specification the post-period consists of 9 months from April-December. Tables C.1, C.2, and C.3 report the estimated coefficients when the post-treatment observations (t_2, t_4) are taken from May-December, June-December, and July-December respectively. The results are robust to the specification used since the coefficients are stable.

Table C.1: Robustness checks: Post-treatment May-Dec

	CO2 int.	High emis.	Diesel	N purchases	Weight	Power	Engine size
Treatment eff	-7.609***	-0.119***	0.208***	-0.420	5.527	0.609*	46.48***
	(0.446)	(0.00658)	(0.00848)	(1.486)	(3.593)	(0.277)	(4.265)
Group effect	-7.853***	-0.0822***	0.177***	-15.56***	49.00***	1.741***	13.34***
	(0.317)	(0.00400)	(0.00738)	(4.590)	(2.483)	(0.220)	(3.802)
Time effect	-6.219***	-0.0627***	0.118***	-18.18***	22.91***	-0.490	-0.150
	(0.508)	(0.00808)	(0.00733)	(5.154)	(4.459)	(0.453)	(6.048)
Gross Inc. (Mun.)	0.0414***	0.000458***	-0.000538***	0.873***	0.197*	0.0341**	0.331*
	(0.0106)	(0.000118)	(0.000147)	(0.258)	(0.0917)	(0.0114)	(0.159)
Diesel/Gas price ratio	-2.419	0.114***	0.192***	-22.47***	70.46***	9.514***	84.83*
	(2.551)	(0.0333)	(0.0284)	(4.387)	(21.03)	(2.358)	(35.93)
Fleet age (County)	-0.117	-0.00143	0.0256***	-2.972	7.663	0.112	9.331
	(0.518)	(0.00636)	(0.00558)	(4.841)	(4.514)	(0.542)	(7.951)
Constant	171.8***	0.218**	-0.182	-141.3*	1130.7***	65.50***	1494.2***
	(6.533)	(0.0829)	(0.0961)	(70.48)	(55.94)	(6.792)	(105.8)
Observations	12829	12829	22152	12829	12829	12829	12829
Adjusted R^2	0.529	0.449	0.335	0.151	0.259	0.126	0.113

Robust standard errors clustered on municipalities.

Table C.2: Robustness checks: Post-treatment Jun-Dec

	CO2 int.	High emis.	Diesel	N purchases	Weight	Power	Engine size
Treatment eff	-7.536***	-0.123***	0.201***	-0.243	3.728	0.670*	45.09***
	(0.452)	(0.00677)	(0.00898)	(1.483)	(3.629)	(0.281)	(4.434)
Group effect	-7.860***	-0.0817***	0.179***	-15.65***	49.63***	1.807***	14.14***
	(0.324)	(0.00410)	(0.00736)	(4.572)	(2.520)	(0.227)	(3.874)
Time effect	-6.323***	-0.0588***	0.129***	-18.53***	25.49***	-0.449	2.233
	(0.533)	(0.00870)	(0.00780)	(5.183)	(4.720)	(0.479)	(6.498)
Gross Inc. (Mun.)	0.0445***	0.000486***	-0.000535***	0.873***	0.222*	0.0370***	0.371*
	(0.0104)	(0.000116)	(0.000154)	(0.257)	(0.0896)	(0.0110)	(0.156)
Diesel/Gas price ratio	-3.401	0.0882*	0.0959***	-19.67***	39.55*	6.177**	43.20
	(2.339)	(0.0361)	(0.0271)	(3.930)	(19.90)	(1.995)	(31.57)
Fleet age (County)	-0.0784	-0.000957	0.0258***	-2.864	8.063	0.155	9.941
	(0.513)	(0.00630)	(0.00570)	(4.770)	(4.435)	(0.530)	(7.769)
Constant	171.3***	0.228**	-0.0996	-145.0*	1146.5***	67.17***	1513.2***
	(6.691)	(0.0847)	(0.0963)	(69.12)	(56.47)	(6.760)	(104.6)
Observations	12059	12059	20820	12059	12059	12059	12059
Adjusted R^2	0.520	0.434	0.337	0.151	0.267	0.140	0.119

Robust standard errors clustered on municipalities.

Table C.3: Robustness checks: Post-treatment Jul-Dec

	CO2 int.	High emis.	Diesel	N purchases	Weight	Power	Engine size
Treatment eff	-7.211***	-0.123***	0.192***	0.0502	3.220	0.783**	46.22***
	(0.441)	(0.00677)	(0.00939)	(1.481)	(3.743)	(0.297)	(4.684)
Group effect	-7.886***	-0.0825***	0.179***	-15.77***	49.27***	1.805***	13.90***
	(0.327)	(0.00418)	(0.00736)	(4.573)	(2.535)	(0.232)	(3.955)
Time effect	-6.778***	-0.0616***	0.137***	-18.97***	25.01***	-0.568	0.447
	(0.553)	(0.00897)	(0.00818)	(5.232)	(4.848)	(0.510)	(6.936)
Gross Inc. (Mun.)	0.0469***	0.000508***	-0.000527***	0.882***	0.238**	0.0392***	0.407**
	(0.0103)	(0.000122)	(0.000152)	(0.257)	(0.0907)	(0.0108)	(0.153)
Diesel/Gas price ratio	-3.433	0.104**	0.111***	-20.90***	45.54*	5.409**	37.63
	(2.321)	(0.0373)	(0.0255)	(3.884)	(19.23)	(1.873)	(30.82)
Fleet age (County)	-0.0494	-0.000735	0.0263***	-2.726	8.408	0.207	11.11
	(0.508)	(0.00635)	(0.00574)	(4.684)	(4.487)	(0.526)	(7.713)
Constant	170.4***	0.206*	-0.120	-147.6*	1133.1***	66.67***	1495.9***
	(6.877)	(0.0894)	(0.0973)	(68.01)	(59.13)	(6.913)	(105.3)
Observations	11280	11280	19487	11280	11280	11280	11280
Adjusted R^2	0.514	0.424	0.332	0.152	0.263	0.146	0.120

Robust standard errors clustered on municipalities.

D Other Figures

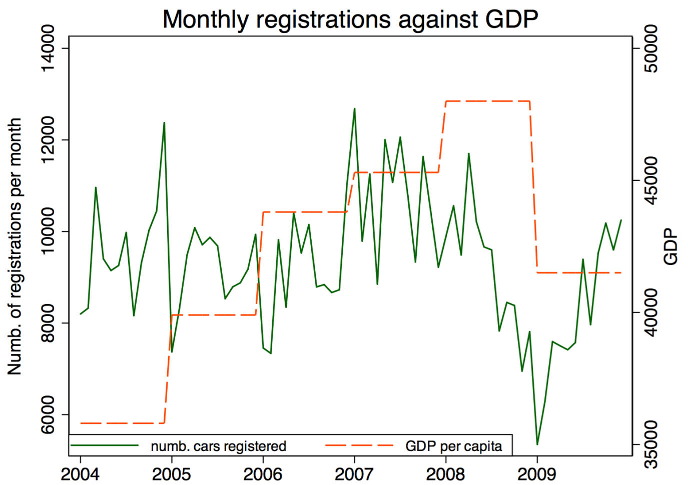

Figure D.1: Graphic correlation between demand for private vehicles expressed in the number of new vehicles registered per month and GDP in Norway between 2004 and 2011. The drop in 2009 is probably due to the economic crisis, which had a mild effect on the Norwegian economy. The sales of vehicles recover strongly in 2009.

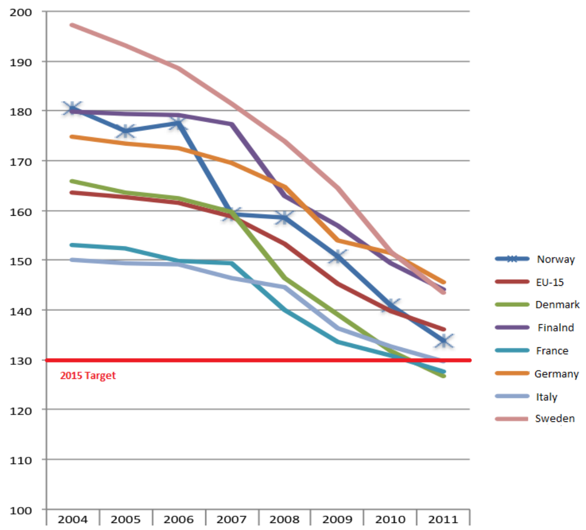

Figure D.2: CO_2 intensity of new registered vehicles: a comparison between European countries. The reduction in CO_2 intensity for new registered vehicles in Norway is in line with the other European countries. Figure from OFV AS and Vista Analyse AS (Rapport 12/42) http://www.regjeringen.no/pages/38231042/vista_rapport2012.pdf

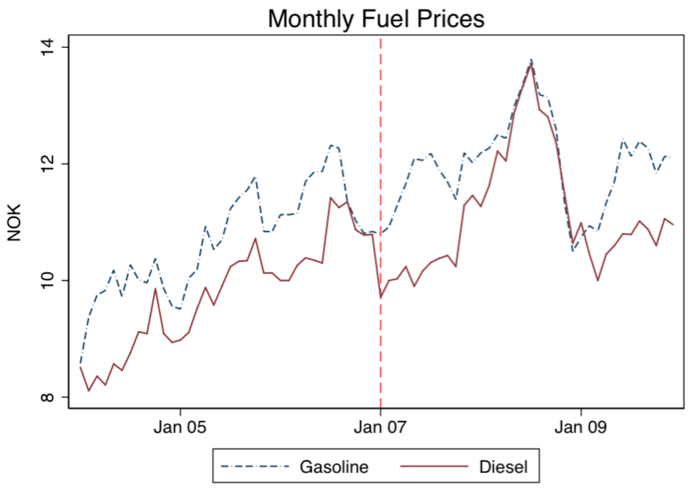

Figure D.3: Monthly fuel prices including taxes.

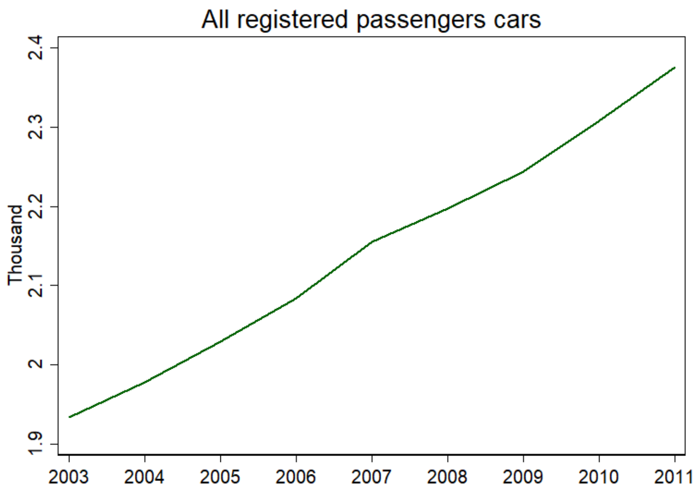

Figure D.4: All registered passenger cars in Norway. Source Statistics Norway (SSB).

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