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# The Effect of Registration Taxes on New Car Sales and Emissions: Evidence from Switzerland

A. Alberini and M. Bareit

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**The Effect of Registration Taxes on New Car Sales and Emissions: Evidence from Switzerland**

By
Anna Alberini and Markus Bareit[1]

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**Abstract.** In Switzerland, the annual circulation taxes on road vehicles are set by and paid to the cantons (not to the federal government). We exploit the 26 different circulation tax rules and their variation over time, which we interpret as a natural experiment, to see if linking them to a vehicle's $CO_2$ emissions rate has helped shift new car sales towards lower-emitting vehicles. We find that even when the penalty associated with a highly polluting vehicle is high, the effect is relatively small. For example, in canton Zurich, imposing a 50% "malus" on the annual registration fee for cars that emit 200 or more grams of $CO_2$ per kilometer reduces the average $CO_2$ emissions rate from new cars by only 0.46 gram per kilometer, bringing it to 158.11 grams per kilometer in 2011. A similar effect would be attained with a modest increase in fuel taxes.

**Keywords**: vehicle demand estimation, fuel economy, fuel taxes, vehicle taxes, carbon dioxide emissions rates

**QEL Classification**: L62, Q4, Q5

1 Alberini (aalberin@umd.edu) is a professor at AREC, University of Maryland, and a research affiliate of the Centre for Energy Policy and Economics (CEPE), ETH Zürich. Bareit (mbareit@ethz.ch) is with CEPE, ETH Zürich.

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## 1. Introduction

In most developed countries road vehicles account for a relatively large share of all emissions of carbon dioxide ($CO_2$), the most important greenhouse gas (IPCC, 2014). Economic theory shows that this externality can be corrected by imposing a tax on it, but since taxes on $CO_2$ emissions from personal road transport are often considered politically and/or practically infeasible (Aldy et al., 2010), research has focused on the effectiveness of alternate policy tools, such as regulations (e.g., fuel economy or emissions standards), fuel taxes, and various types of incentives towards the purchase of "clean" vehicles and the retirement of more polluting ones (Anderson et al., 2011).

In several countries, the incentives take the form of one-off excise taxes on the purchase of new vehicles (Brand et al., 2013), with the tax rate positive and high for high emitters and low (or even negative) for low emitters, as in France (Klier and Linn, 2015; D'Haltfoueiulle et al., 2014), Finland (Stitzing, 2015), Sweden (Huse and Lucinda, 2013; Klier and Linn, 2015), the Netherlands (Kok, 2015), Denmark (Mabit, 2014) and/or an annual registration fee (also termed circulation tax[2]) linked to the $CO_2$ emissions rates of the vehicle, as in the UK, Germany, and Sweden (Cerruti et al., 2015; Klier and Linn, 2015; Kok, 2015). In principle, all of these fees can be structured as feebates, where the revenues from imposing taxes on high emitters are used to finance refunds to low emitters (Anderson et al., 2011).

Assessments of the impacts of such taxes or subsidies usually rely on discrete choice models of car purchases based on individual-level data (e.g., Mabit, 2014), models of shares of vehicles sold as a function of vehicle characteristics (including price, fuel costs, and others)

2 In this paper, we use the terms registration fee and circulation tax interchangeably. It is understood that either would be paid on an annual basis.

derived from random utility models (e.g., Berry, 1994; Chandra et al., 2010), and structural approaches where discrete choice models describe the demand side and first-order conditions for maximum profits the supply side (Huse and Lucinda, 2013; Stitzing, 2015; Adamou et al., 2014). These models are sometimes modified to allow for consumer preferences to be heterogeneous and to account for driver or car unobservables (Berry et. al., 1995).

Econometric identification is a key issue in all of these models. Some have exploited exogenous tax changes (Huse and Lucinda, 2013; Klier and Linn, 2015; Ciccone, 2014). Alternatively, in the absence of legislative or programmatic changes and the associated shocks, the effect of an excise tax is computed from the coefficient on price in a structural discrete choice model of car sales, as in Adamou et al. (2014).

In this paper, we exploit a unique situation that provides variation across vehicle models, over time, and across jurisdictions, to estimate the effects of annual circulation fees that reward the owners of low-polluting vehicles and penalize those who purchase high emitters. Our study locale is Switzerland, where the jurisdictions are the 26 cantons, which are responsible for establishing and levying the annual vehicle registration taxes. Implicit in this authority is the ability to modify such fees to promote the adoption of fuel-efficient, low-emissions cars. As a result Switzerland has 26 different car registration tax systems which differ in their calculation base (e.g., engine size, horsepower, weight, etc.) and rates.

During our study period (2005 - 2011), none of the cantons imposed vehicle circulation fees *directly* and *solely* linked to $CO_2$ emissions rates.[3] However, by the end of 2011, a total of 11 cantons had introduced circulation fee systems meant to promote the adoption of fuel-efficient, low-emissions cars. Adoption took place in different years in the various cantons. Essentially, the

[3] One canton introduced one such system in 2014. By contrast, a system where the annual registration fees depend entirely on the vehicle's CO2 emissions rate was established in the UK in 2001. Vehicles were placed in different CO2 emissions bands, and were required to pay annual registration fees that were higher for higher bands. The system is still in place. The bands were changed over time and the fees, called "Vehicle Excise Duty" (VED), were changed over time and across bands (Cerruti et al., 2016).

cantons kept their existing tax systems, which are mainly based on the car's weight, engine displacement or performance (and in general penalize heavy, inefficient vehicles), and enhanced these implicit incentives by granting rebates for low-emitting[4] and/or energy-efficient cars and/or charging extra fees for high-emitting or inefficient cars. The exact criteria for such "bonuses" and "maluses" vary across cantons, and are sometimes based on fuel efficiency and in other cases on the $CO_2$ emissions rates (or a combination of both; see Appendix A).[5]

In this paper we examine the effect of these bonus/malus systems using data on the sales of new vehicles in Switzerland from 2005 to 2011. We have information about the first registration of individual cars, including the exact date, municipality and canton. We exploit the variation in the registration tax rebates across cantons and over time to investigate whether they have resulted in a shift towards more fuel-efficient vehicles with lower emissions. We wish to see if bonuses have encouraged the sale of relatively fuel-efficient and clean cars, and maluses have discouraged the sales of fuel-inefficient and high-emitting vehicles. We deploy a Berry (1994) type of model, where the identification of the effect of the registration fee-based policies comes from the variation within a canton over time and across car models, and across cantons.

Earlier studies that have assessed the effect of registration fees based on $CO_2$ emissions used data at the national level and were forced to restrict attention to short study periods to avoid capturing the effects of other nationwide policies and events. In most cases they were not able to exploit the variation across jurisdictions because the policies being studied were established at the

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4 In this paper we use the expressions low-emitting and clean cars always in terms of their $CO_2$ emissions. We are aware that policies with the goal to reducing average $CO_2$ emissions can lead to a higher share of diesel cars which may have higher emissions rates for local pollutants such as $NO_x$, PM10 and other.

5 Consider, for example, an Audi Q5, a sport utility vehicle that is available with either diesel or gasoline powertrain. In canton Geneva, in 2008 the annual registration fee for a gasoline Q5 was 692.8 Swiss Francs (CHF). In 2009, the registration fee for a gasoline Q5 ranged between CHF 692.8 and 1070.8, averaging CHF 818.8. In 2010, it ranged between CHF 546,2 and 1641.3, averaging 964.9 CHF. The annual registration fee for a diesel Q5 ranged from CHF 354.2 to 879.2 in 2008, and from CHF 472.3 to 860.8 in 2009 and 2010. For comparison, in canton Zurich the annual registration fee for a gasoline Q5 remained between CHF 395 and CHF 557.5 in each of those years. (All amounts in constant 2011 CHF.) Over those years, the emissions rate of an Audi Q5 ranged between 162 and 218 grams of $CO_2$ per km.

national level. Our study is thus the first to use within-country variation in a natural experiment type of setting.

Klier and Linn (2015) report that manufacturers were relatively unresponsive to the establishment of key "cutoffs" for the registration tax in France, Germany and Sweden, in the sense that they did not appear to introduce a significant number of models just below those cutoffs in response to the policy. We expect this to be the case in Switzerland, which is a small car market[6] and one where foreign manufacturers and importers would be most unlikely to alter production to follow the variation in policies across cantons.

Our results show that car sales do respond to bonus and malus policies. We use the estimated results to calculate the impact of a hypothetical 50% increase in circulation taxes for high $CO_2$ emitters in canton Zurich on its average $CO_2$ emissions, predicting that the average $CO_2$ emissions rate of new cars would be reduced by only about half a gram per kilometer. The total $CO_2$ emissions would be reduced by around 764 tons per year. Even though on average the malus itself happens to be in the ballpark of the optimal tax, the cost of these emissions reductions would be high—about 800 CHF per ton. This is well above the cost of abatement, which the Swiss federal government estimates to be 113 CHF/ton (ARE, 2016). A similar exercise for Geneva shows that the malus attains reductions of 422 tons of $CO_2$ per year, while the bonus can be credited with reductions of 159 tons of $CO_2$ per year.

We believe that these results are of interest because they illustrate the (limited) potential of bonus/malus programs in a federal system where the emissions-based fees are not coordinated across sub-federal jurisdictions. The United States is one such system, although of course it

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[6] In 2011, Swiss new car registrations accounted for 2.3% of all new car registrations in Europe (EU27 member states and EFTA countries). Source: http://www.acea.be/uploads/press_releases_files/20120117_PRPC-FINAL-1112.xls

differs from Switzerland in terms of population, stock of cars, size of the new car market, and in that it does have a domestic automaking industry.

The remainder of this paper is organized as follows. Section 2 presents background and policy information. Section 3 describes the model and policy calculations. Section 4 presents the data. Section 5 reports the estimation results, and section 6 concludes.

## 2. Background

Like many other countries, Switzerland has sought to reduce its $CO_2$ emissions from road transport through a number of programs at the federal and cantonal level. Many of these programs are targeted at fuel economy, as a vehicle's $CO_2$ emissions are perfectly proportional to its fuel consumption rate, the proportionality factor being a function of the vehicle's fuel. Others target $CO_2$ emissions rate directly, and others yet both at the same time.[7]

For example, a voluntary agreement between the Federal Department of the Environment, Transport, Energy and Communications (DETEC) and the association of Swiss car importers (auto-schweiz) was established in 2002 with the goal of reducing $CO_2$ emissions rates and improving the fuel economy of vehicles by 2008. These efforts failed to produce results and the agreement is generally regarded as a failure (BFE, 2009). It was thus replaced by mandatory $CO_2$ emissions standards, similar to those adopted in the European Union (EU), which oblige car importers to reduce the average $CO_2$ emissions of their new cars fleet to 130 grams per kilometer by 2015. This new program was introduced in July 2012 (BFE, 2011).

In 2003, the Swiss Federal Office of Energy established a program based on fuel economy/emissions labels. The energy label must be affixed to each new car prior to its sale. There are a total of seven energy categories, ranging from A (best) to G (worst). Each car is

[7] In some cantons, reduced registration fees apply to cars that have an A label (see below; also see Alberini et al., 2016) and meet a specified $CO_2$ emissions rate threshold.

placed in the appropriate category based on its rating score, which is computed as a weighted average of its absolute fuel consumption rate (liters of fuel per 100 km) and relative fuel consumption rate (per 1000 kg of car weight). The label conveys information about fuel economy and emissions to prospective car buyers, and contains an implicit normative message, since the car's fuel economy and emissions "performance" is compared with that from all of the other cars in Switzerland.

Turning to cantonal policies, between 2005 and 2011 (our study period) several cantons reformed their car registration tax systems with the goal to provide incentives to buy fuel-efficient, low-$CO_2$ emissions cars. For example, several cantons offer discounts on the annual circulation fee to fuel efficient, "clean" (i.e., low-emissions) cars and have raised the fees for "guzzlers" and high-emitting vehicles. These discounts and penalties differ in their amounts and eligibility criteria (e.g., incentives for A-label cars, incentives for cars emitting less than 130 grams of $CO_2$ per kilometer, a combination of label and $CO_2$ incentives, etc.). Some cantons have implemented special tax bonuses for cars with alternative fuels, like hybrid electric vehicles, vehicles that run on natural gas or plug-in electric vehicles.

Eleven out of the 26 Swiss cantons implemented a bonus and/or malus system based on $CO_2$ emissions or fuel-efficiency criteria during our study period, namely 2005-2011.[8] As can be seen in Appendix A, these policies were adopted in different years in the different cantons, and the specifics of the annual circulation tax and associated incentive for fuel-efficient and clean cars vary across cantons.

The vehicle registration taxes and the accompanying bonus/malus systems are adopted through revisions of the cantonal laws. The revised laws come into force shortly after the final decision in the cantonal parliament, and thus we argue that in most cases the tax changes are

[8] After 2011, six more cantons implemented such a bonus/malus system.

unanticipated by consumers. In some cases, a cantonal referendum may be called to amend the cantonal laws or repeal the decisions of the cantonal parliament. Even so, the process is relatively expeditious and it generally takes no longer than a year for the circulation tax reform to become effective.

## 3. The Model

We use the variation in annual circulation fees across cantons, over time and across vehicles to identify their effects on the sales of new cars, and specifically of each make-model-trim-variant (i.e., "TARGA approval number").

Following Berry (1994), we assume that the utility of consumers is linear in car characteristics, $\mathbf{w}_i$, and price $p_i$. In equation (1) below, ε is an error term that is i.i.d. type I extreme value:

$$V_i = \mathbf{w}_i \boldsymbol{\alpha} + p_i \delta + \varepsilon_i \qquad (1)$$

It is straightforward to show that the share of sales of vehicle $i$ in year $t$ is

$$s_{it} = \frac{\exp(\mathbf{x}_{it}\boldsymbol{\beta})}{1 + \sum_{j=1}^{J} \exp(\mathbf{x}_{jt}\boldsymbol{\beta})} \qquad (2)$$

and that of the "out of market good" is

$$s_{0t} = \frac{1}{1 + \sum_{j=1}^{J} \exp(\mathbf{x}_{jt}\boldsymbol{\beta})}, \qquad (3)$$

where $\mathbf{x}$ subsumes car attributes $\mathbf{w}$ and price $p$, and $\boldsymbol{\beta}$ their respective marginal utilities. On taking logs and subtracting (3) from (2), we obtain:

$$\ln s_{it} - \ln s_{0t} = \mathbf{x}_{it}\boldsymbol{\beta}, \text{ or} \qquad (4)$$

$$\ln s_{it} = \ln s_{0t} + \mathbf{x}_{it}\boldsymbol{\beta}. \qquad (5)$$

Equation (5) is further simplified because both $s_{it}$ and $s_{0t}$ contain the same denominator, which results in

$$\ln Sales_{it} = \ln Sales_{0t} + \mathbf{x}_{it}\boldsymbol{\beta}, \qquad (6)$$

where $Sales_{0t}$ denotes the sales of the "out of market" good. We append an error term and enter a number of terms to proxy for ln $Sales_{0t}$. Specifically, we estimate variants on the regression equation:

$$\ln Sales_{ict} = \beta_1 \cdot \ln P_{it} + \beta_2 \cdot \ln VRT2_{ict} + \beta_3 \log FC_{ict} + \mathbf{z}_{ict}\boldsymbol{\gamma} + FE_{ict} + e_{ict} \qquad (7)$$

where *i* denotes the make-model-trim-variant, *c* the canton, and *t* is the year. *P* is the vehicle price, *VRT2* the annual registration tax (which varies across the cantons, and within the canton over time and across models), *FC* is the annual fuel cost (which depends on the vehicle fuel efficiency, fuel type and fuel price in year *t*), and **z** is a vector of car characteristics, such as horsepower, weight, body type, etc.

We add a rich set of fixed effects (FE) in hopes of capturing ln $Sales_{0t}$, accounting for unobserved heterogeneity as well as demand and supply shocks, and making both the price and the circulation fee exogenous (conditional on the effects). In our broadest specification, these are make-model, canton-by-year, class-by-year, class-by-canton, and make-by-canton fixed effects, which account for population, popularity of certain classes of vehicles (nationally over time and across regions) due to trends or geography, and cultural factors that influence car purchases (for instance, German-made cars may be more popular in the German-speaking regions, etc.). We also include dummies for certain top-selling make-model-trims (e.g., certain variants of the VW Golf).[9] In a slightly simplified specification, the year fixed effects enter in the model only additively, and not interacted with canton or class effects. This latter specification thus includes

[9] Failure to include these top seller dummies results in estimated models that seriously underpredict sales for the more popular cars. Most of these top sellers are extremely popular models in all of Europe.

top-seller dummies, and make-model, canton, year, class-by-canton and make-by-canton fixed effects.

Including canton-specific effects (alone or interacted with time or other car characteristics) allows us to regard the circulation fees, which are set at the cantonal level, as exogenous (conditional on the effects). In practice, we believe that this assumption is reasonable, as conventional wisdom suggests that in Switzerland circulation fees have historically been used primarily as a source of tax revenue and have typically changed little in response to changes in car sales or trends in emissions levels from new cars.

We estimate equation (7) using two possible methods. Both rely on the fact that the Berry model assumes that car attributes are exogenous. First, under the assumption that price is exogenous, conditional on the fixed effects, we run least squares.[10] Next, we instrument for price. As in Berry, Levinsohn and Pakes (1995), our instruments are 1) each attribute, 2) the average of that attribute over all other cars within the same class by the same manufacturer, and 3) the average of that attribute over all cars within the same class by the other manufacturers.

We note that equation (7) assumes that circulation tax discounts and penalties have symmetric effects, that a car buyer reacts to 1-CHF change in annual costs in the same fashion—whether it comes from the registration fee or changes in the price of fuel, and that prospective car buyers react in the same fashion to the annual circulation fee—whether it is linked to carbon dioxide emissions rate, fuel economy, or any other factor. We also estimate further variants of equation (7) where the registration fee and the fuel costs are combined into a single variable—either the sum of annual fuel and registration costs, or the discounted flow of such annual figures

[10] GMM estimation is also possible, but we do not deploy it here.

over the lifetime of the car.[11] Clearly, these latter specifications maintain the same assumptions in terms of responsiveness to monetary variables and sources of the registration fees.

We use the estimated coefficients, and the procedure outline in Appendix B (based on the marginal effect of the circulation fees and on the conditional logit model underlying equations (1)-(6)),[12] to compute the effect of 1) introducing a 50% increase of the circulation tax for cars that emit more than 200 grams $CO_2$ per km in canton Zurich in 2011, 2) removing the 50% penalty on the same types of cars in canton Geneva in 2011, and 3) removing the discount on low emitters in canton Geneva in 2011. We use 2) and 3) to assess the impact of the policy that canton Geneva actually did start in 2010.

We conduct the three abovementioned exercises on individual cantons because the Swiss constitution does not envision a circulation tax at the federal level, and because traditionally the cantons have been setting the circulation taxes independently of one another. Moreover, car owners are legally obliged to register their car and pay the circulation tax in the canton where they reside. We focus on cantons Zurich and Geneva because of their relatively large populations and car stocks, similar new car $CO_2$ emissions rates (see Figure 1), and because the former has no policy in place—which allows us to predict what would happen if Zurich adopted the Geneva system. For good measure, we also repeat the Zurich exercise with two small, and geographically isolated, cantons, Uri and Solothurn, where imposing the policy would have no nationwide

[11] Annual fuel costs are computed assuming that gasoline cars are driven 12,000 kilometers a year, whereas diesel cars are driven 16,000 kilometers a year. These figures are based on the 2010 Mobility Survey of Switzerland. We use the manufacturer-specified combined city and highway fuel economy, and the actual fuel price in the year of the purchase. Lifetime annual costs assume that these figures apply for each year of the life of the vehicle and use a discount rate of 5%. Based on a recent study by Kolli et al. (2010), we assume that the average life of a gasoline is 13.64 years and that of a diesel car is 10.76 (which are consistent with more lifetime kilometers from a diesel engine). The notion that current fuel prices are expected for the foreseeable future is consistent with evidence from surveys about drivers' expectations about future fuel prices (Anderson et al., 2011).

[12] Implicit in the conditional logit model is the independent of irrelevant alternatives assumption, which imposes strict substitution patterns among alternatives. We hope to relax this assumption in future extensions of this research.

consequences. Attention in this paper is restricted to new car sales. We do not attempt to quantify the possible impacts on the used car market.[13]

## 4. The Data

The dataset used in this study is created by merging different datasets provided by the Federal Statistics Office (FSO) and the Federal Roads Office (FEDRO). The merged dataset contains detailed information on all new passenger cars registered in Switzerland from 2005 to 2011. For each car, we have the make, model, trim and variant, along with weight, engine size, horsepower, body, powertrain, fuel economy and $CO_2$ emissions rate. FSO and FEDRO do not collect information about the price paid for each car, so we append manufacturer-suggested retail prices (MSRPs) as documented by the Swiss Touring Club. We assign the appropriate energy label to each vehicle using the federal laws in place at the time of the vehicle's registration, and compute the annual registration tax for each vehicle based on the cantonal laws in place at the time of the vehicle's first registration.

Based on the fact that we have extensive information about each vehicle but little or no information in terms of the individual who bought it, we tally the sales for each type of car (make-model-trim-variant) in each canton in any given year.[14] This results in a panel dataset where the cross-sectional unit is a make-model-trim-variant in a given canton. We follow each such unit over a study period that starts in 2005 and ends in 2011. The panel is unbalanced because new "models" (or, to be precise, make-model-trim-variants) are introduced and others are discontinued by the manufacturer or importer during the study period.

[13] Alberini et al. (2016) examine the effects of bonus/malus systems on the retirement of old and high-emitting (inefficient) vehicles.

[14] Other studies have examined monthly sales nationwide (Huse and Lucinda, 2013) or quarterly data, also at the national level (Klier and Linn, 2015). We prefer annual sales at the cantonal level because shorter time periods, like the month or quarter, resulted in few or no sales for many make-model-trims.

Attention is restricted to diesel and gasoline passenger vehicles with up to nine seats.[15] We only keep the observations for which the merge between MOFIS (the car registration dataset) and TARGA (the car attributes dataset) was successful, and for which there appears to be a valid zipcode. We stop at 2011 to be able to focus on the canton registration schemes and to avoid confounding with the national-level policy $CO_2$ emissions scheme that started in 2012.

This leaves us with 1,765,590 new car registrations, or roughly 91% of total new registrations between 2005 and 2011. We were able to attach price information for 1,757,785 (99.56% of them). When we construct the panel to document annual sales by make-model-trim-variant, we get a total of 623,882 observations.[16]

Table 1 reports the total number of sales by year. For example, a total of 260,360 cars that meet our requirements were sold in 2011. Table 2 displays the top 12 makes, which collectively account for over 65% of the sales during our study period. German makes account for 35% of the sales.

Regarding $CO_2$ emissions, Figure 2 displays the average (sales-weighted) $CO_2$ emissions rates by year. It is clear that they have been declining over time, although as of 2011 they remain well above 150 g $CO_2$/km – and well above their counterparts for France, Italy, the UK and even Germany (Alberini et al., 2016).

In our sample, 0.32% of the new cars sold have $CO_2$ emissions rates below 100 g/km, 11.25% between 101 and 130 g/km, 19.82% between 131 and 150, 47.24% between 151 and 200, 15.58% between 201 and 250, and 5.78% are 250 and higher. Figure 3 shows how the shares by emissions rate bracket have changed from the beginning to the end of our study period: It is clear that the distribution has shifted to the left, namely towards the lower emissions rates. In Figure 1

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15 Hybrid electric, plug-in electric, ethanol-85 and other fuels account for less than 1% of all models.

16 If the same identical car is bought by 100 different persons in a given canton in 2005, for example, that's one observation (in lieu of the original 100 registrations), and 100 sales, for the year 2005.

we compare the distribution of $CO_2$ emissions categories in the two largest cantons, Zurich and Geneva. The distribution is remarkably similar across these cantons.

Table 3 shows the shares of sales of new cars by class. From 2005 to 2011, the market shares of subcompacts and SUVs have increased, whereas that of compact cars has decreased and the others have changed little. A comparison between Zurich and Geneva cantons suggests that the market shares of subcompacts and SUVs are about 5 percentage points larger in Geneva canton.

Descriptive statistics for key variables are displayed in Table 4. Among other things, Table 4 shows that there is considerable variation in the annual circulation tax applied by the various cantons and across vehicle models: The annual circulation tax ranges from zero to almost 5,500 CHF, and in part because of this, and in part because of the fluctuations in motor fuel prices (shown in Figure 4), the annual expenditure on the circulation tax and fuel ranges from 771 to almost 9,500 CHF. Summary statistics of the annual registration fees are reported in Appendix C.

**5. Results**

Our main regression results are displayed in Table 5. All regressions include car characteristics and fixed effects. Regressions labeled (1) include the full set of fixed effects, whereas those labeled (2) include the slightly simplified set of fixed effects. T statistics are based on standard errors clustered at the canton level. Panel (A) reports the results for equation (7). The coefficients have the expected signs, plausible magnitudes, and are very stable across specifications (1) and (2).

The coefficient on log circulation fees can be interpreted as an elasticity, and indicates that a one percent increase in the registration fee results a 0.08 decline in the number of sales.

This coefficient, when compared to that on log fuel costs, suggests that the same effect as with a 50% increase in registration fee in a given canton (the size of the malus in our policy exercises below) could be attained by increasing fuel costs by 16%. In other words, a 32% increase in the fuel tax, which currently account for about half of the price of motor fuel in Switzerland,[17] would secure the same effect as a dramatic increase in the annual registration tax.[18] We remind the reader that this assumes that people respond in the same fashion to a change in annual costs, whatever the source and type of annual cost.

In panel (B) we present an alternate model that combines circulation fee and annual fuel costs. The coefficient on the log of these combined costs is negative and strongly significant. Its magnitude (-0.28 to -0.33) is comparable to but stronger than that of log annual fuel costs in (A). Replacing log annual costs with log lifetime costs (panel (C)) yields similar results.

We report the results of instrumental variable estimation in Table 6.[19] While the coefficients on log price change dramatically with respect to their counterparts in table 5, [20] the coefficients on fuel costs and registration fee (separately or combined) are remarkably stable and similar to those displayed in Table 5.

Equation (7) and its empirical counterparts in Table 5 assume that sales respond symmetrically to a “bonus” (a discount on the circulation tax) and to a “malus” (an increase in the circulation fee). We empirically test if this is the case by adding an interaction between log circulation fee (or log annual costs) and an indicator that this vehicle is subject to a malus. As

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[17] See http://www.afdc.energy.gov/data/10327

[18] These calculations consider a single canton, and do not take into account the fact that a change in the federal motor fuel tax rates would also affect car purchases in other cantons.

[19] We remind the reader that there are two reasons for instrumenting for price. The first is that the automakers and auto importers set the price endogenously to influence sales, and the second is the possibility of price mismeasurement, since we do not observe actual and individual transaction and the only price variable available to us us the manufacturers’ suggested retail price.

[20] Adamou et al. (2014) report similar results in their study of German car sales.

shown in Table 7, the coefficient on this interaction is negative and statistically significant at the conventional levels, but its practical importance is negligible.

One concern with any policy is the possibility of anticipation effects. As discussed previously, in Switzerland, the decision to change the cantonal circulation tax and link it with fuel economy and/or emissions may be subject to a referendum and imply a “turnaround” time of about one year. To see if anticipation effects are important, we re-run our main regressions after excluding from the sample the observations from the year before the policy is implemented (if the canton is an adopting canton). The results (displayed in Table 8) are similar to their counterparts with the full sample, suggesting that anticipation effects did not play an important role in shaping new car sale patterns.

Finally, we check if restricting the sample to pre-policy years (in adopting cantons) plus all years from non-adopting cantons changes the coefficients on the key variables. Indeed, as shown in Table 9, panel (A), the coefficients on log circulation fees and log annual costs get stronger, but we believe that this an artifact likely due to the virtual absence of variation over time within a canton. Further excluding observations from cantons that eventually reform their circulation tax system (panel (B)) produces almost identical results.

Our policy exercise below is based on the results from OLS estimation and panels (A) and (B) in Table 5. We assume a policy that introduces a 50% malus on cars with emissions rates greater than 200 g $CO_2$/km. Attention is restricted to 2011, and we focus on cantons with no prior policy, such as Zurich. We hold all other fees in Zurich and all other cantons’ registration schemes unchanged. We further assume that households buy no more than one vehicle in a year (new or used), so that the sales of the “outside good” are the number of households, minus the new car sales, in canton Zurich.

Using the model of panel (A) or that of panel (B) in Table 5 produces remarkably close predictions. For this reason, in the remainder of this section we present and discuss the predictions based on (B). Introducing the malus reduces the sales of passenger vehicles with more than 200 g $CO_2$/km by 262 units. The revenue to the canton from this type of vehicles actually *increases* from CHF 2.156 million to CHF 3.233 million, as the reduction in sales is more than compensated by the larger fee. The sales of cars with emissions rates below 200 g CO2/km increase by 18 units. Annual $CO_2$ emissions are thus reduced by 764 tons. This is a reduction of less than one percent that brings the average emissions rate of all new cars sold in canton Zurich from 158.58 g $CO_2$/km to 158.12 g $CO_2$/km. The change is thus less than half a gram per kilometer.

One important question is what the cost of the emissions reductions is. This is correctly calculated as the welfare loss for those who would have purchased high-emissions cars in the absence of the malus but turn to some other model when the malus is imposed. We measure this with the change in consumer surplus, which has been shown to be a reasonable approximation to the correct welfare measure (equivalent variation) (West and Williams, 2004), and is the area of the "triangle" under the demand curve between initial and final sales, and annual costs with and without the malus.[21] This area must be calculated for each make-model-trim-variant with emissions rate greater than 200 g/km and then aggregated over all such vehicle types. Our calculations show that the cost is 810 CHF for each ton of $CO_2$ emissions abated. This is much higher than the cost of $CO_2$ abatement, which the Swiss Federal Office for Spatial Development ARE estimates to be 113 CHF/ton (ARE, 2016).

[21] In practice, our equation (6) is a log-log demand function, and it is straightforward to show that the consumer surplus loss is $(AC_1 \cdot q_1 - AC_0 \cdot q_0)$-$(AC_1 - AC_0)\cdot q_1$, where AC denotes annual costs, q denotes sales, and the subscript 0 and 1 denote the situations without and with the malus, respectively.

If we assume a 50% malus in canton Solothurn, the model predicts an annual emissions reduction of about 100 tons, and 35 fewer high-emitting cars sold per year (a change of less than half of one percent). The average $CO_2$ emissions rate from all new cars would decline by 0.31 grams per kilometer. In canton Uri, the effect of the malus is to reduce the sales of high-emitting vehicles by 3 units and $CO_2$ emissions by about 10 tons per year. The average $CO_2$ emissions rate for new cars in canton Uri would decrease by 0.25 grams per kilometer.

Our models predict that introducing the malus in canton Geneva reduces the sales of high-pollution cars by 136 units per year, $CO_2$ emissions by 422 tons per year (a 1.4% reduction), and the average $CO_2$ emissions rate by 0.85 grams per kilometer. The bonus system is credited with increasing the sales of low-emissions vehicles by 107 units per year, reducing $CO_2$ emissions by 159 tons per year and average $CO_2$ emissions rate from 159.55 to 159.19 g/km (a reduction of less than half a gram per kilometer). The bonus system implies a loss of revenue for the canton, while the malus increases the tax revenue.

## 6. Conclusions

We have estimated a model of new car sales in Switzerland using sales at the cantonal level by make-model-trim-variant. The model is based on Berry (1994), which in turn is based on conditional logit. We exploit the natural experiment represented by the Swiss cantons' different tax systems and their variation across cantons and over time within a canton during our study period, which is the result of these systems' reforms at different times. We use a rich set of fixed effects to capture unobserved heterogeneity and make price exogenous, conditional on car attributes and the effects.

The model is well-behaved and predicts that imposing a malus on cars with sufficiently high $CO_2$ emissions rates (over 200 g/km, or 10% of the new cars) does reduce the sales of such cars and the associated emissions. The effect, however, is very small and results in minimal reductions in the $CO_2$ emissions rates from new cars in the canton that adopts the malus policy. Because of the relatively low elasticity of sales with respect to the registration fee or total annual costs, the malus actually raises cantonal revenues. The opposite is true for a bonus, which—at least in canton Geneva—reduces $CO_2$ emissions by a lesser extent than the malus.

At least for canton Zurich, we find that the emissions reductions would come at a high cost—some 800 CHF/ton. Taken together with the modest reduction in $CO_2$ emissions, this suggests that individual canton policies focusing on vehicles registration have limited potential. We believe that this is the case even though on average the malus itself happens to be in the ballpark of the optimal tax. To further elaborate on this, Switzerland-specific estimates of the marginal damage of $CO_2$ are 75 - 100 CHF (2010 CHF;[22] see Ecoplan and Infras, 2014).[23] For the

[22] On applying the CPI for Switzerland this figure is practically the same in 2011 CHF, as the CPI rose by only 0.3% from 2010 to 2011Price Index: http://www.bfs.admin.ch/bfs/portal/en/index/themen/05/02/blank/key/basis_aktuell.html

[23] Ecoplan and Infras (2014) mention that these are only comparative figures that contain several uncertainties. These costs cover only the climate damages in Switzerland. The average future costs of climate change are compared with the $CO_2$ emissions in Switzerland in 2010.

average malus car owner, the optimal annual malus would thus be 333 CHF.[24] This is in the ballpark of the average malus that would have to be paid by a Zurich driver (288 CHF) if the malus were simply 50% of the base registration fee, as we have assumed in the above exercise. Even more important, our estimates suggest that a modest increase in motor fuel costs (about 16%, which, holding the kilometer driven and the pre-tax price of fuel the same, is equivalent to a 32% increase in the fuel tax) would be sufficient to engender the same effect as a 50% increase in registration taxes in Zurich.

24 The average Swiss driver drives his or her car 14,000 km a year. At marginal damage values below 100 CHF, the average Zurich malus car owner would pay less than 333 CHF to register his car. This amount is based on 14,000 km a year, an average $CO_2$ emissions rate of 237.7251 g/km, and a tax of 100 CHF for each ton of $CO_2$ generated.

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## Appendix A. Circulation tax features in the Swiss cantons.

**Table A.1: Cantonal incentives based on registration tax for all fuel types from 2005 to 2011**

| Canton | | Tax base* | Incentives for of fuel efficient cars of all fuel types between 2005 and 2011 | |
|---|---|---|---|---|
| | | | Year of policy introduction | Incentive |
| Aargau | AG | Steuerps | no policy | |
| Appenzell A. Rh. | AI | Mass | no policy | |
| Appenzell I. Rh. | AR | Mass | 2011 | 50% Bonus if $CO_2$ ≤130g/km |
| Bern | BE | Mass | no policy | |
| Basel-Landschaft | BL | Mass | no policy | |
| Basel-Stadt | BS | Steuerps | no policy | |
| Freiburg | FR | Ed | 2011 | 100% Bonus if label A; 2.2% additional tax if D, E, F, G or no label |
| Genf (Geneva) | GE | Steuerps | 2010 | 50% Bonus if $CO_2$ ≤120g; 50% Malus if $CO_2$ >200g |
| Glarus | GL | Ed | no policy | |
| Graubünden | GR | tg_hubraum | 2009 | 2009: 80% Bonus if $CO_2$ ≤140g & PM10≤0.01g; 60% Bonus if $CO_2$ ≤160g & PM10≤0.01g;<br>2011: 80% Bonus if $CO_2$ ≤120g & PM10≤0.01g; 60% Bonus if $CO_2$ ≤140g & PM10≤0.01g |
| Jura | JU | Mass | no policy | |
| Luzern | LU | Steuerps | no policy | |
| Neuenburg | NE | mass & ed | no policy | |
| Nidwalden | NW | Ed | 2009 | 100% Bonus (for first 3 years) if label A |
| Obwalden | OW | Ed | 2009 | 100% Bonus (for first 3 years) if label A; 50% Bonus (for first 2 years) if label B; 60.- Malus if label G or no label |
| St. Gallen | SG | Mass | 2009 | 100% Bonus if label A & $CO_2$ ≤130g (for 3 years) |
| Schaffhausen | SH | Ed | no policy | |
| Solothurn | SO | Ed | no policy | |
| Schwyz | SZ | Ed | no policy | |
| Thurgau | TG | Ed | 2011 | 50% Bonus if label A (max. 5 years); 25% Bonus if label B (max. 5 years); 50% Malus if label F or G |
| Tessin | TI | mass & perform | 2009 | 50% Bonus if label A & $CO_2$ ≤140g (+filter); 20% Malus if label F; 50% Malus if label G |
| Waadt | VD | mass & perform | 2005 | 50% Bonus if $CO_2$ ≤120g |
| Wallis | VS | Ed | 2010 | 50% Bonus if label A & $CO_2$ ≤130g |
| Uri | UR | Mass | no policy | |
| Zug | ZG | Ed | no policy | |
| Zürich | ZH | Ed | no policy | |

* Explanation of the different bases:
- Steuerps: engine displacement × 0.005093
- Mass: total weight in kilogram
- ed: engine displacement in ccm
- perform: Performance in kilowatt

**Appendix B. Calculation of changes in sales and $CO_2$ emissions reductions associated with specific policies.**

We do our calculations for 2011, focusing on one specific canton at a time (e.g., Zurich). The policy is a 50% Malus for cars emitting >200g $CO_2$/km.

In our formulae below, the subscript k applies to all affected cars (cars with emissions rates > 200g/km) while the subscript m denotes all non-affected cars (with emissions rates less than or equal to 200g/km).

**Change in the share of a specific car affected by the policy:**

$$\Delta share_k = s_k \cdot (1 - s_k) \cdot \beta \cdot \Delta \ln \text{Annualcosts}_k + \sum_{j \neq k} (-s_k \cdot s_j) \cdot \beta \cdot \Delta \ln \text{Annualcosts}_j$$

**Change in number of vehicles k sold:**

$$\Delta cars_k = N \cdot \Delta share_k$$

**Change in CO2 emissions from cars k**

$$\Delta CO_{2k} = \Delta cars_k \cdot CO_2 \cdot km$$

where km denotes the annual kilometers driven, and is equal to 12,000 km for gasoline cars and 16,000 km for diesel cars.

**Total change in emissions from all cars covered by the policy:**

$$\Delta CO_{2K} = \sum_{k=1}^{K} \Delta CO_{2k}$$

**Change in the share of a specific car not covered by the policy:**

$$\Delta share_m = -s_k \sum_{k=1}^{K} s_j \cdot \beta \cdot \Delta \ln \text{Annualcosts}_k$$

**Change in number of cars m sold:**

$$\Delta cars_m = N \cdot \Delta share_m$$

**Change in $CO_2$ emissions from cars m**

$$\Delta CO_{2m} = \Delta cars_m \cdot CO_2 \cdot km$$

**Total change in emissions**

$$\Delta CO_{2M} = \sum_{m=1}^{M} \Delta CO_{2m}$$

**Final effect on CO2 emissions**

$$\Delta CO_{2final} = \Delta CO_{2K} + \Delta CO_{2M}$$

**Loss of revenue due to the malus on cars affected by the policy**

$$L_k = \Delta cars_k \cdot tax_k \cdot Malusfactor$$

**Total revenue loss**

$$L_K = \sum_{k=1}^{K} L_k$$

**Gain in revenue from non-affected cars**

$$G_m = \Delta cars_m \cdot tax_m$$

**Total revenue gain**

$$G_M = \sum_{m=1}^{M} G_m$$

**Net revenue**

$$Net\ revenue = L_K - G_M$$

## Appendix C. Registration fees

**Table C.1: Registration tax after policy in 2005 (weighted by number of registrations)**

| Canton | | Average | Minimum | Median | Maximum |
|---|---|---|---|---|---|
| Aargau | AG | 292 | 172 | 287 | 768 |
| Appenzell I. Rh. | AI | 483 | 191 | 470 | 838 |
| *Appenzell A. Rh.* | *AR* | *528* | *269* | *529* | *952* |
| Bern | BE | 605 | 340 | 605 | 1003 |
| Basel-Landschaft | BL | 495 | 245 | 490 | 910 |
| Basel-Stadt | BS | 432 | 132 | 429 | 1131 |
| *Freiburg* | *FR* | *425* | *275* | *427* | *1130* |
| *Genf* | *GE* | *285* | *158* | *270* | *1343* |
| Glarus | GL | 384 | 210 | 389 | 1010 |
| *Graubünden* | *GR* | *569* | *298* | *545* | *1501* |
| Jura | JU | 567 | 332 | 566 | 906 |
| Luzern | LU | 380 | 212 | 371 | 1361 |
| Neuenburg | NE | 398 | 200 | 388 | 1344 |
| *Nidwalden* | *NW* | *343* | *153* | *325* | *1095* |
| *Obwalden* | *OW* | *342* | *191* | *338* | *886* |
| *St. Gallen* | *SG* | *472* | *214* | *471* | *869* |
| Schaffhausen | SH | 251 | 115 | 252 | 711 |
| Solothurn | SO | 378 | 202 | 368 | 1033 |
| Schwyz | SZ | 398 | 205 | 366 | 996 |
| *Thurgau* | *TG* | *275* | *138* | *275* | *733* |
| *Tessin* | *TI* | *481* | *202* | *446* | *2217* |
| Uri | UR | 334 | 170 | 334 | 612 |
| *Waadt* | *VD* | *523* | *119* | *496* | *1679* |
| *Wallis* | *VS* | *222* | *119* | *224* | *635* |
| Zug | ZG | 349 | 172 | 315 | 776 |
| Zürich | ZH | 395 | 191 | 377 | 1355 |
| Total | | 424 | 115 | 388 | 2217 |

**Table C.2: Registration tax of policy and no-policy cantons in 2005 (weighted by number of registrations)**

| Canton | Average | Minimum | Median | Maximum |
|---|---|---|---|---|
| No-policy Cantons | 424 | 115 | 377 | 1361 |
| Policy Cantons | 425 | 119 | 408 | 2217 |

**Table C.3: Registration tax after policy in 2011 (weighted by number of registrations)**

| Canton | | Average | Minimum | Median | Maximum |
|---|---|---|---|---|---|
| Aargau | AG | 276 | 180 | 252 | 828 |
| Appenzell I. Rh. | AI | 484 | 206 | 488 | 950 |
| *Appenzell A. Rh.* | *AR* | *513* | *145* | *558* | *1010* |
| Bern | BE | 638 | 366 | 639 | 1050 |
| Basel-Landschaft | BL | 675 | 356 | 671 | 1223 |
| Basel-Stadt | BS | 407 | 184 | 368 | 1219 |
| *Freiburg* | *FR* | *306* | *0* | *376* | *1454* |
| *Genf* | *GE* | *518* | *94* | *354* | *5705* |
| Glarus | GL | 370 | 220 | 339 | 944 |
| *Graubünden* | *GR* | *466* | *66* | *523* | *1620* |
| Jura | JU | 601 | 402 | 593 | 970 |
| Luzern | LU | 366 | 239 | 353 | 1331 |
| Neuenburg | NE | 401 | 234 | 369 | 1319 |
| *Nidwalden* | *NW* | *256* | *0* | *280* | *1273* |
| *Obwalden* | *OW* | *223* | *0* | *184* | *1310* |
| *St. Gallen* | *SG* | *419* | *0* | *484* | *910* |
| Schaffhausen | SH | 242 | 120 | 216 | 684 |
| Solothurn | SO | 363 | 225 | 334 | 1218 |
| Schwyz | SZ | 336 | 200 | 320 | 560 |
| *Thurgau* | *TG* | *224* | *84* | *216* | *1332* |
| *Tessin* | *TI* | *506* | *117* | *437* | *4565* |
| Uri | UR | 360 | 184 | 362 | 643 |
| *Waadt* | *VD* | *542* | *139* | *517* | *1794* |
| *Wallis* | *VS* | *205* | *63* | *195* | *755* |
| Zug | ZG | 338 | 204 | 330 | 917 |
| Zürich | ZH | 373 | 200 | 346 | 1175 |
| Total | | 429 | 0 | 395 | 5705 |

**Table C.4: Registration tax of policy and no-policy cantons in 2011 (weighted by number of registrations)**

| Canton | Average | Minimum | Median | Maximum |
|---|---|---|---|---|
| No-policy Cantons | 424 | 120 | 383 | 1331 |
| Policy Cantons | 435 | 0 | 419 | 5705 |

**Table C.5: Registration tax after policy in 2005 (not weighted by number of registrations)**

| Canton | | Average | Minimum | Median | Maximum |
|---|---|---|---|---|---|
| Aargau | AG | 320 | 172 | 287 | 1020 |
| Appenzell I. Rh. | AI | 481 | 191 | 472 | 907 |
| *Appenzell A. Rh.* | *AR* | *573* | *234* | *561* | *1048* |
| Bern | BE | 637 | 296 | 632 | 1003 |
| Basel-Landschaft | BL | 523 | 223 | 514 | 910 |
| Basel-Stadt | BS | 473 | 132 | 429 | 1498 |
| *Freiburg* | *FR* | *486* | *244* | *427* | *1588* |
| *Genf* | *GE* | *313* | *158* | *270* | *1343* |
| Glarus | GL | 437 | 210 | 389 | 1518 |
| *Graubünden* | *GR* | *610* | *298* | *545* | *2002* |
| Jura | JU | 615 | 332 | 612 | 969 |
| Luzern | LU | 427 | 212 | 371 | 1705 |
| Neuenburg | NE | 486 | 193 | 435 | 1634 |
| *Nidwalden* | *NW* | *373* | *153* | *325* | *1517* |
| *Obwalden* | *OW* | *389* | *191* | *351* | *1194* |
| *St. Gallen* | *SG* | *500* | *214* | *491* | *869* |
| Schaffhausen | SH | 284 | 115 | 252 | 974 |
| Solothurn | SO | 430 | 165 | 384 | 1407 |
| Schwyz | SZ | 417 | 205 | 366 | 1374 |
| *Thurgau* | *TG* | *308* | *115* | *275* | *1008* |
| *Tessin* | *TI* | *570* | *202* | *519* | *2485* |
| Uri | UR | 359 | 148 | 350 | 669 |
| *Waadt* | *VD* | *598* | *119* | *552* | *1785* |
| *Wallis* | *VS* | *252* | *119* | *224* | *836* |
| Zug | ZG | 346 | 161 | 315 | 1007 |
| Zürich | ZH | 420 | 191 | 377 | 1355 |
| Total | | 447 | 115 | 387 | 2485 |

**Table C.6: Registration tax of policy and no-policy cantons in 2005 (not weighted by number of registrations)**

| Canton | Average | Minimum | Median | Maximum |
|---|---|---|---|---|
| No-policy Cantons | 452 | 115 | 427 | 2485 |
| Policy Cantons | 444 | 115 | 384 | 1705 |

**Table C.7: Registration tax after policy in 2011 (<u>not</u> weighted by number of registrations)**

| Canton | | Average | Minimum | Median | Maximum |
|---|---|---|---|---|---|
| Aargau | AG | 314 | 180 | 300 | 1068 |
| Appenzell I. Rh. | AI | 518 | 200 | 512 | 950 |
| *Appenzell A. Rh.* | *AR* | *574* | *145* | *601* | *1097* |
| Bern | BE | 680 | 315 | 680 | 1050 |
| Basel-Landschaft | BL | 720 | 306 | 712 | 1223 |
| Basel-Stadt | BS | 462 | 138 | 449 | 1569 |
| *Freiburg* | *FR* | *372* | *0* | *423* | *1663* |
| *Genf* | *GE* | *648* | *94* | *386* | *5705* |
| Glarus | GL | 430 | 220 | 407 | 1590 |
| *Graubünden* | *GR* | *509* | *66* | *570* | *2097* |
| Jura | JU | 657 | 348 | 657 | 1015 |
| Luzern | LU | 423 | 222 | 389 | 1785 |
| Neuenburg | NE | 492 | 202 | 449 | 1749 |
| *Nidwalden* | *NW* | *286* | *0* | *310* | *1588* |
| *Obwalden* | *OW* | *268* | *0* | *284* | *1310* |
| *St. Gallen* | *SG* | *466* | *0* | *525* | *910* |
| Schaffhausen | SH | 278 | 120 | 264 | 1020 |
| Solothurn | SO | 423 | 173 | 402 | 1473 |
| Schwyz | SZ | 350 | 160 | 360 | 560 |
| *Thurgau* | *TG* | *284* | *72* | *240* | *1584* |
| *Tessin* | *TI* | *643* | *117* | *556* | *4565* |
| Uri | UR | 386 | 158 | 379 | 700 |
| *Waadt* | *VD* | *639* | *139* | *602* | *2082* |
| *Wallis* | *VS* | *233* | *63* | *235* | *875* |
| Zug | ZG | 343 | 169 | 330 | 1055 |
| Zürich | ZH | 414 | 200 | 395 | 1419 |
| Total | | 454 | 0 | 405 | 5705 |

**Table C.8: Registration tax of policy and no-policy cantons in 2011 (<u>not</u> weighted by number of registrations)**

| Canton | Average | Minimum | Median | Maximum |
|---|---|---|---|---|
| No-policy Cantons | 447 | 0 | 423 | 5705 |
| Policy Cantons | 459 | 120 | 402 | 1785 |

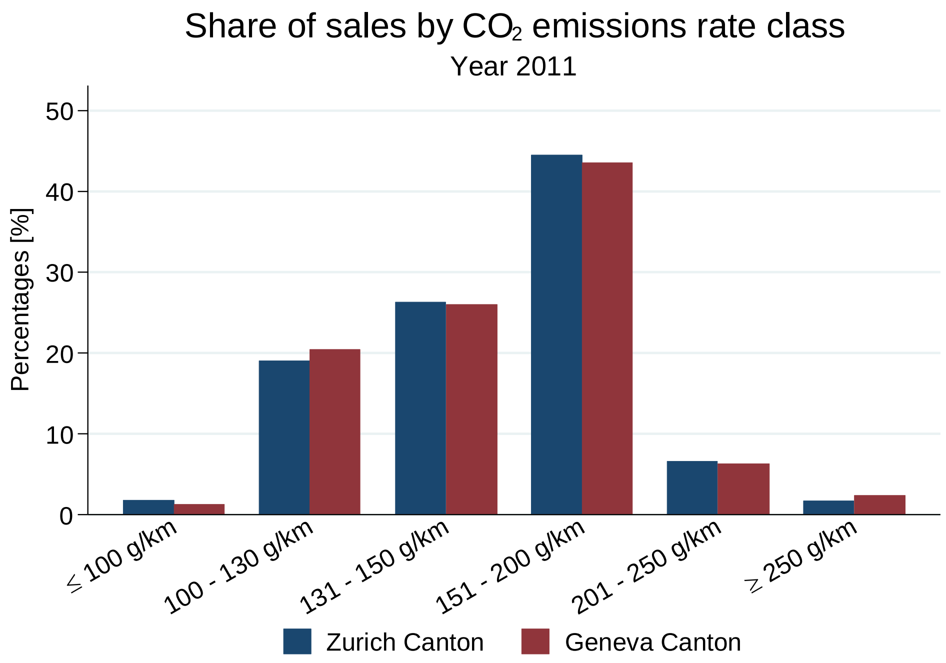


**Figure 1: Shares of sales by CO2 emissions rate class**

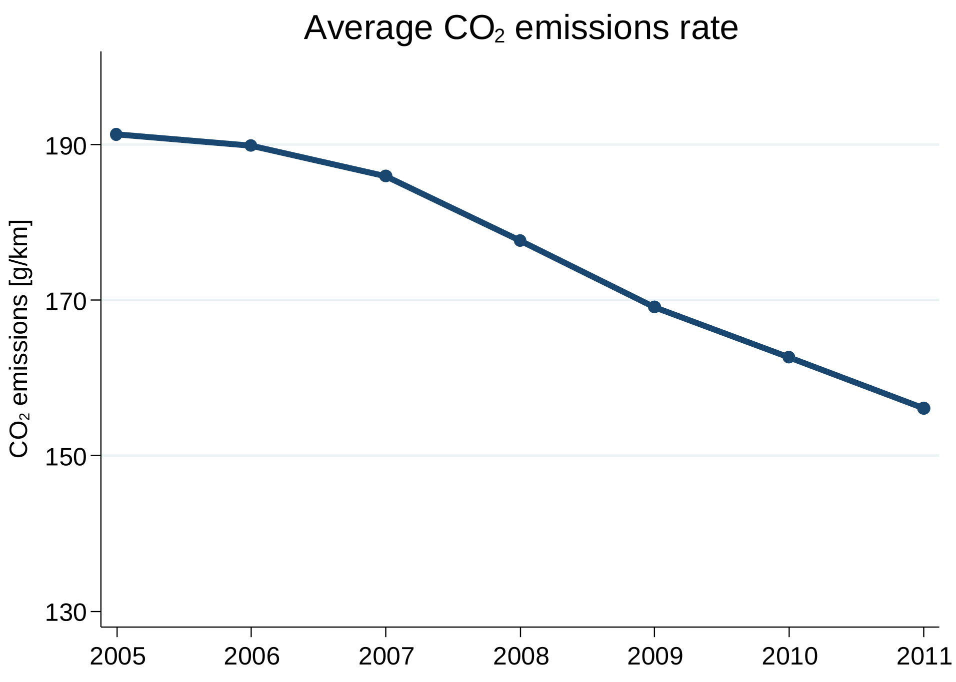


**Figure 2: Sales-weighted average $CO_2$ emissions rate by year**

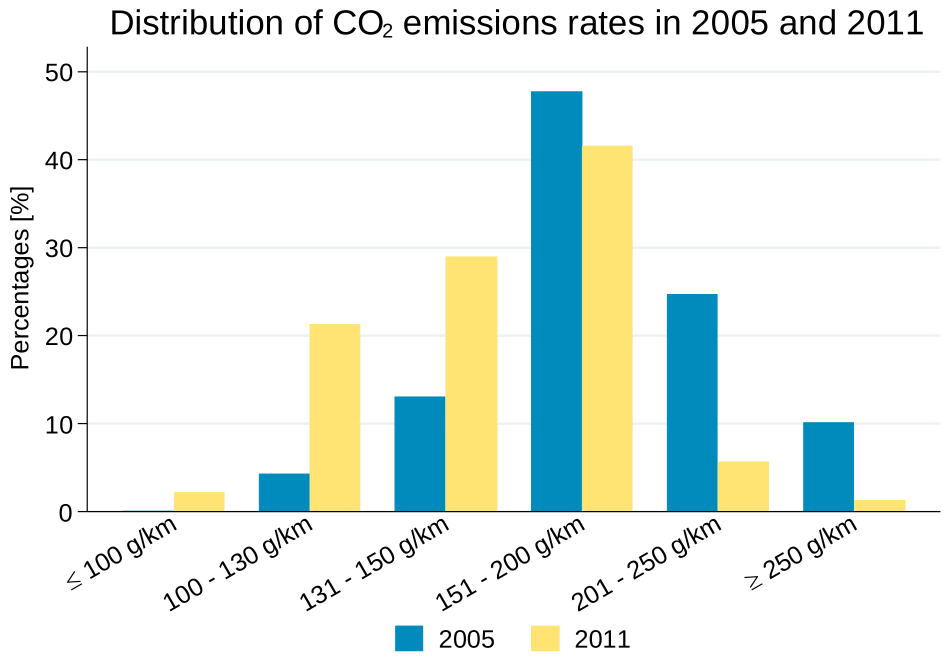


**Figure 3: Distribution of $CO_2$ emissions rates in 2005 and 2011**

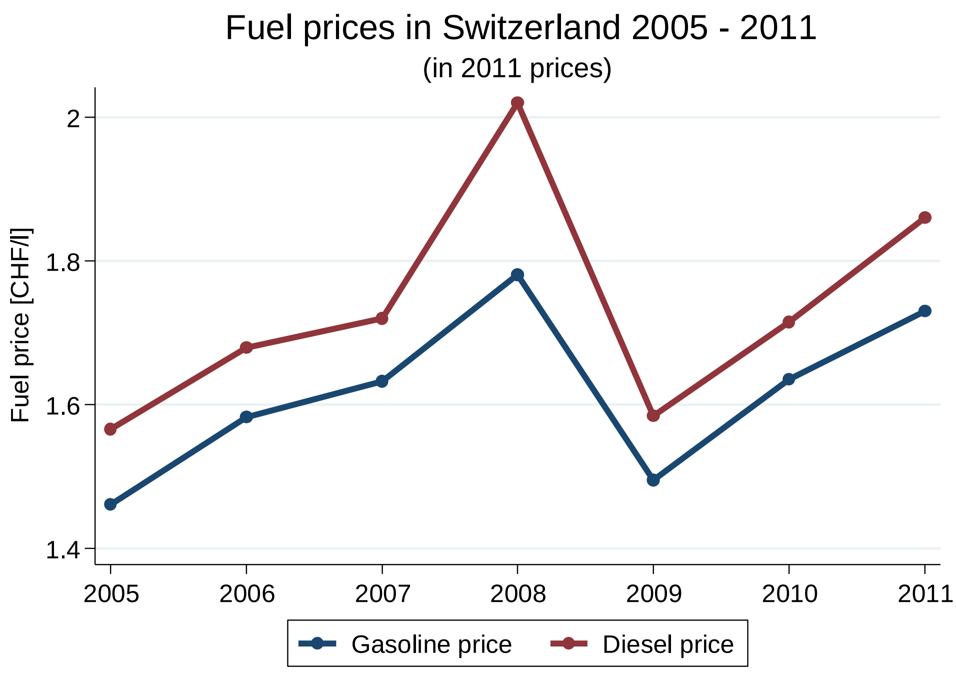


**Figure 4: Motor fuel prices in Switzerland (2005-2011)**

**Table 1: Sales of gasoline and diesel cars by year**

| Year | total number of sales |
|---|---|
| 2005 | 235836 |
| 2006 | 233896 |
| 2007 | 249758 |
| 2008 | 256449 |
| 2009 | 237542 |
| 2010 | 260931 |
| 2011 | 260360 |
| Total | 1734772 |

**Table 2: Average annual sales and market shares by make. Diesel and gasoline cars, 2005-2011**

| Make | Average annual sales | Share of sales |
|---|---|---|
| VW | 71,193.75 | 11.41 |
| Opel | 38,602.33 | 6.19 |
| Audi | 35,749.36 | 5.73 |
| BMW | 35,181.50 | 5.64 |
| Renault | 33,498.78 | 5.37 |
| Toyota | 31,127.35 | 4.99 |
| Peugeot | 30,742.19 | 4.93 |
| Ford | 30,082.26 | 4.82 |
| Mercedes | 29,567.98 | 4.74 |
| Citroen | 26,176.28 | 4.2 |
| Fiat | 24,080.34 | 3.86 |
| Skoda | 24,102.63 | 3.86 |

**Table 3: Market shares (sales-weighted). Diesel and gasoline.**

| | 2005-2011 | 2005 | 2011 | Zurich 2011 | Geneva 2011 |
|---|---|---|---|---|---|
| micro car | 6.11 | 3.68 | 5.98 | 5.77 | 6.42 |
| subcompact | 22.23 | 18.17 | 25.00 | 21.84 | 25.84 |
| compact | 23.94 | 29.83 | 17.27 | 19.05 | 16.92 |
| midsize | 14.71 | 15.45 | 13.96 | 16.90 | 10.38 |
| full size | 6.04 | 6.88 | 5.54 | 8.06 | 5.81 |
| SUV | 15.56 | 12.72 | 18.69 | 16.4 | 21.1 |
| minivan | 11.72 | 13.3 | 13.81 | 12.18 | 13.8 |

**Table 4: Descriptive Statistics (not sales-weighted)**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Sales per Canton | 285,706 | 6.071878 | 13.8519 | 1 | 619 |
| Engine Size | 285,706 | 121.1678 | 58.42276 | 30 | 493 |
| Diesel Share | 285,706 | 0.37247 | 0.483464 | 0 | 1 |
| Automatic | 285,706 | 0.323812 | 0.46793 | 0 | 1 |
| Total Weight (kg) | 285,706 | 2012.71 | 383.8706 | 850 | 3500 |
| Annual Costs | 285,706 | 2143.962 | 623.5441 | 771.3685 | 9488.719 |
| Registration Tax | 285,706 | 471.6291 | 247.378 | 0 | 5446.8 |
| Price | 285,706 | 46692.77 | 34403.89 | 9567.751 | 778000 |

**Table 5: Main Regressions. Selected coefficients and t statistics. Dependent variable: log sales of a specified make-model-trim-variant. Nobs=254,731.**

| | (A) | | | (B) | | | (C) | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | (1) | (2) | ($2^*$) | (1) | (2) | ($2^*$) | (1) | (2) | (2*) |
| Log price | -0.163 | -0.124 | -0.124 | -0.168 | -0.128 | -0.128 | -0.165 | -0.124 | -0.124 |
| | (-7.965) | (-6.096) | (-5.140) | (-8.282) | (-6.341) | (-4.790) | (-8.098) | (-6.176) | (-4.86) |
| Log fuel costs | -0.219 | -0.251 | -0.251 | | | | | | |
| | (-8.15) | (-10.014 | (-4.250) | | | | | | |
| Log circulation fee | -0.072 | -0.082 | -0.082 | | | | | | |
| | (-5.803) | (-7.401) | (-2.010) | | | | | | |
| Log annual costs | | | | -0.278 | -0.331 | -0.331 | | | |
| | | | | (-11.072) | (-14.035) | (-4.720) | | | |
| Log lifetime costs | | | | | | | -0.319 | -0.368 | -0.368 |
| | | | | | | | (-11.956) | (-14.636) | (13.21) |
| <u>Fixed effects:</u> | | | | | | | | | |
| Canton-by-year | Yes | No | No | Yes | No | No | Yes | No | No |
| Class-by-year | Yes | No | No | Yes | No | No | Yes | No | No |
| Class-by-canton | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Make-by-canton | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Canton | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |
| Year | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |

*t* statistics in parentheses
[*] All regressions control for car characteristics.
[**] In the column labeled ($2^*$), we display t statistics based on standard errors clustered around the canton.

**Table 6: Estimation results instrumenting for car price (2SLS).**

| | (1) | (2) | (3) |
|---|---|---|---|
| log price | -2.466 | -2.468 | -2.448 |
| | (-17.38) | (-17.52) | (-17.37) |
| log fuel costs | -0.240 | | |
| | (-9.62) | | |
| log circulation fee | -0.0679 | | |
| | (-6.08) | | |
| log annual costs | | -0.305 | |
| | | (-12.95) | |
| log lifetime costs | | | -0.338 |
| | | | (-13.48) |
| Fixed effects: | | | |
| Canton | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Class | Yes | Yes | Yes |
| Class-by-canton | Yes | Yes | Yes |
| Make-by-canton | Yes | Yes | Yes |
| Observations | 254,731 | 257,241 | 257,241 |

*t* statistics in parentheses

**Table 7: Checking asymmetry: Selected coefficients and t statistics. Dependent variable: log sales of a specified make-model-trim-variant. Nobs=254,731**

| | (A) | | | (B) | | |
|---|---|---|---|---|---|---|
| Variable | (1) | (2) | (2*) | (1) | (2) | (2*) |
| Log price | -0.165 | -0.125 | -0.125 | -0.17 | -0.129 | -0.129 |
| | (-8.043) | (-6.15) | (-5.20) | (-8.381) | (-6.41) | (-4.88) |
| Log fuel costs | -0.219 | -0.251 | -0.251 | | | |
| | (-8.174) | (-10.015) | (-4.23) | | | |
| Log circulation fee | -0.058 | -0.073 | -0.073 | | | |
| | (-4.576) | (-6.404) | (-1.71) | | | |
| Log circulation fee (malus) | -0.019 | -0.014 | -0.014 | | | |
| | (-4.737) | (-3.878) | (-1.98) | | | |
| Log annual costs | | | | -0.259 | -0.318 | -0.318 |
| | | | | (-10.105) | (-13.27) | (-4.51) |
| Log annual costs (malus) | | | | -0.013 | -0.01 | -0.01 |
| | | | | (-3.8) | (-3.288) | (-1.73) |
| Fixed effects: | | | | | | |
| Canton-by-year | Yes | No | No | Yes | No | No |
| Class-by-year | Yes | No | No | Yes | No | No |
| Class-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Make-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Canton | No | Yes | Yes | No | Yes | Yes |
| Year | No | Yes | Yes | No | Yes | Yes |

*t* statistics in parentheses
[*] All regressions control for car characteristics.
[**] In the column labeled (2*), we display t statistics based on standard errors clustered around the canton.

**Table 8: Checking for anticipation effects: The sample excludes the year before the policy is implemented (in adopting cantons). Selected coefficients and t statistics. Dependent variable: log sales of a specified make-model-trim-variant**

| | (A) | | | (B) | | |
|---|---|---|---|---|---|---|
| Variable | (1) | (2) | (2*) | (1) | (2) | (2*) |
| Log price | -0.176 | -0.136 | -0.136 | -0.182 | -0.140 | -0.140 |
| | (-8.333) | (-6.476) | (-5.35) | (-8.682) | (-6.745) | (-5.000) |
| Log fuel costs | -0.217 | -0.246 | -0.246 | | | |
| | (-7.806) | (-9.463) | (-4.26) | | | |
| Log circulation fee | -0.061 | -0.076 | -0.076 | | | |
| | (-4.754) | (-6.564) | (-1.75) | | | |
| Log annual costs | | | | -0.262 | -0.318 | -0.318 |
| | | | | (-10.131) | (-13.07) | (-4.460) |
| Fixed effects: | | | | | | |
| Canton-by-year | Yes | No | No | Yes | No | No |
| Class-by-year | Yes | No | No | Yes | No | No |
| Class-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Make-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Canton | No | Yes | Yes | No | Yes | Yes |
| Year | No | Yes | Yes | No | Yes | Yes |
| Observations | 240,018 | 240,018 | 240,018 | 242,528 | 242,528 | 242,528 |

*t* statistics in parentheses
[*] All regressions control for car characteristics and include dummies for top-selling make-models (e.g., VW Golf).
[**] In the column labeled (2*), we display t statistics based on standard errors clustered around the canton.

**Table 9: No policy only: The sample in panel (a) excludes the years after the policy is implemented (in adopting cantons). The sample in panel (b) includes only observations from non-adopting cantons. Selected coefficients and t statistics. Dependent variable: log sales of a specified make-model-trim-variant**

| | (a) only when policy is not in place (for adopting cantons) + non-adopting cantons | | | (b) only non-adopting cantons | | |
|---|---|---|---|---|---|---|
| Variable | (A) | (B) | ($B^*$) | (A) | (B) | ($B^*$) |
| Log price | -0.124 | -0.13 | -0.13 | -0.11 | -0.122 | -0.122 |
| | (-5.533) | (-5.828) | (-5.21) | (-4.118) | (-4.544) | (-4.65) |
| Log fuel costs | -0.202 | | | -0.214 | | |
| | (-7.331) | | | (-6.426) | | |
| Log circulation fee | -0.295 | | | -0.346 | | |
| | (-16.019) | | | (-13.05) | | |
| Log annual costs | | -0.441 | -0.441 | | -0.442 | -0.442 |
| | | (-14.434) | (-6.26) | | (-11.804) | (-5.72) |
| Fixed effects: | | | | | | |
| Canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| Class-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Make-by-canton | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 208,957 | 208,957 | 208,957 | 144,187 | 144,187 | 144,187 |

*t* statistics in parentheses

[*] The models include car characteristics and dummies for top-selling make-models (e.g., VW Golf),

[**] In the columns labeled ($B^*$), we display t statistics based on standard errors clustered around the canton.

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