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The Impact of Emissions-Based Taxes on the Retirement of Used and Inefficient Vehicles: The Case of Switzerland

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Abstract

Many countries have adopted policies designed to reduce CO_2 emissions from road vehicles. Taxes linked to the CO_2 emissions rate or the fuel economy of a vehicle (which is inversely related to its CO_2 emissions rate) are examples of such policies. These taxes are usually imposed on new vehicles, and previous evaluations have estimated the increases in the shares or sales of new and fuel-efficient vehicles associated with such taxes. In contrast, we ask whether taxes on new cars that penalize high emitters induce changes in the retirement of used and inefficient vehicles. We exploit natural experiment conditions in Switzerland to analyze the impact of two different "bonus"/"malus" schemes implemented at the cantonal level. In both schemes, the bonus rewards new efficient vehicles. The malus is retroactive in canton Obwalden, in the sense that it is charged on both new and existing high-emitting cars, but it is only applied prospectively to new cars in Geneva. We use a difference-in-difference design within a survival analysis setting. We find that a bonus/malus accelerates the retirement of existing high-emitting vehicles in Obwalden, shortening the expected lifetime of the three most popular make-models by 7 to 11 months. The effect is the opposite in Geneva, where we estimate that the expected lifetime of these three popular models is *extended* by 5 to 8 months. These findings have important implications about the desirability of bonus/malus schemes and on their design, as well as on old car scrappage programs.

Keywords: Vehicle retirement, Emissions-based taxes; bonus/malus; difference-in-difference; survival analysis; Switzerland

JEL: L62, Q4, Q5

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1 Introduction

Carbon dioxide (CO_2) emissions are a main cause of climate change (Pachauri and Reisinger, 2007). In developed countries, about one third of these emissions are generated by the transportation sector (Jacobsen and van Benthem, 2015), and Switzerland is no exception (SAEFL, 2004; SFOE Energy, 2014). Consequently, improving the fuel economy of vehicles is considered an attractive alternative for the purpose of reducing CO_2 emissions, as a vehicle's CO_2 emissions rate is inversely related to its fuel economy.

This can be accomplished through setting more stringent fuel economy standards or through taxation—for example, by linking taxes on the purchase of vehicles or annual registration fees to the fuel economy and/or emissions performance of the vehicle. While fuel economy standards are applied only to automakers, taxes can be applied to automakers and importers (as with the guzzler tax in the US) as well as consumers, through one-time taxes on the purchase of vehicles or annual registration fees (Anderson et al., 2011).

In some cases, the taxes are implemented in the form of a feebate, where a tax (fee) on fuel-inefficient vehicles (also called a "malus") is used to finance subsidies (rebates) on fuel-efficient or low-emitting vehicles (also called a "bonus"). A bonus/malus may be designed to be revenue-neutral by ensuring that the outflows associated with the bonus are financed through the revenues obtained from the malus (Anderson et al., 2011; Gillingham, 2013) but an emissions-linked tax does not need to finance outflows.[5]

[5] Gillingham (2013) shows that bonus/malus schemes can be designed to mimic fuel economy standards. However, this result may not imply revenue-neutrality of the bonus/malus. In addition, both fuel economy standards and bonus/malus schemes may trigger rebound effects.

Vehicle taxes based on the vehicle's emissions *rate* are in place in Germany, Finland, Ireland, Norway and the UK, where they were first introduced in 2009, 2008, 2005, 2007, and 2001, respectively.[6] Bonus/malus systems are in place in Sweden, France, Switzerland, and Canada, where they were established in 2006, 2008, 2005, and 2010, respectively.[7]

These schemes are becoming increasingly popular because they may i) provide continuing incentives to increase fuel economy as new technology is developed, which fuel economy standards cannot do (Greene et al., 2005); and ii) yield faster adjustments in behavior in comparison to policies that target producers, such as fuel economy standards (Zachariadis and Clerides, 2015). Disadvantages include that i) alternatives such as gasoline taxes may be more effective because they apply to all cars and penalize *total* emissions, which depend on the car's emissions rate and the miles driven, rather than merely emissions *rates*; and ii) bonus/malus programs are most frequently applied only to new vehicles (see Zachariadis and Clerides, 2015; Gillingham, 2013).

Evaluations of vehicle tax schemes linked with each vehicle's emissions rate or fuel-economy have for the most part been done through ex-ante, simulation-based evaluations of bonus/malus schemes (Habibi et al., 2015; Zachariadis and Clerides, 2015; Adamou et al., 2014; and Adamou et al., 2012). In general, these studies have explored the impacts of alternative bonus/malus schemes on outcome variables such as market shares, CO_2 emissions, consumer welfare, public revenues, and firm profits. A drawback of these studies is that the simulated vehicle markets are based on data from markets that have not experienced feebates schemes at all. Predictions are based on key structural parameters, such as the responsiveness of demand to

[6] Details on these specific policies are provided by Klier and Linn (2015), Stitzing (2015), Ciccone (2015), and Rogan et al. (2011).

[7] Details of these specific policies are provided by Klier and Linn (2012), D'Haultfoeuille et al. (2013), Huse and Lucinda (2013), and Rivers and Schaufele (2014). The Swiss case is described in this paper and Alberini et al. (2016b).

prices, registration taxes, and fuel costs, that often assume that a dollar is a dollar, regardless of the sources of expenditure, their “salience” to consumers (Sallee, 2014), and the possibility that consumers may react asymmetrically to the bonus and malus incentives (Rivers and Schaufele, 2014).

A second trend in the literature has carried out ex-post evaluations of actual emissions-linked taxes (Klier and Linn, 2015; Stitzing, 2015; Ciccone, 2015; Rivers and Schaufele, 2014, and Rogan et al., 2011; and Cerruti et al., 2016) or bonus/malus schemes (Klier and Linn, 2015; D’Haultfoeuille et al., 2014, Huse and Lucinda, 2013; and Alberini and Bareit, 2016). All of these studies have focused on the effects on the sales of new cars, even though imposing taxes on new cars presumably has effects on the used car market and on scrappage rates (Bento et al., 2013).

In this paper, we examine whether annual registration fees based on the vehicle’s emissions rates have an effect on the lifetime (and hence the scrappage rates) of *existing* high-emitting, fuel-inefficient cars. Specifically, do malus schemes on highly polluting and inefficient vehicles slow down or hasten the retirement of old and inefficient vehicles? Retirement would be slowed down if the taxes on new vehicles raise the cost of new and inefficient vehicles relative to that of existing vehicles with comparable emissions levels or fuel economy. Individuals who prefer such high-emitting vehicles (presumably because they are larger, heavier and more powerful) might then hold on to the old vehicles longer. This phenomenon has been observed in other settings (Gruenspecht, 1982) and when fuel economy standards raise the price of new cars relative to the price of old cars (Anderson et al., 2011).

To answer this question, we take advantage of a natural experiment context in Switzerland, where different cantons implemented bonus/malus schemes with different features and in different years. We focus on two such bonus/malus schemes. Our study differs from previous evaluations in three respects, namely the outcome variable of interest (the lifetime of old vehicles, rather than the sales of new ones), the identification strategy, and the type of econometric models used.

Switzerland's political system provides quasi-experimental conditions. As part of a federal republic, the 26 Swiss cantons autonomously design and implement the annual vehicle registration fees. By 2015 sixteen cantons had tied their annual vehicle circulation tax to vehicles' fuel economy or CO_2 emissions rate, which means that by that year there were 16 different bonus/malus schemes in Switzerland. We restrict attention to the bonus/malus schemes implemented by the cantons of Obwalden and Geneva, which were launched in 2009 and 2010, respectively. Since we observe all vehicle registrations in Switzerland from 2005 to 2013, selecting these two cantons allows enough time to elapse since the beginning of the scheme for vehicle owners to adjust their vehicle holdings—something that wouldn't be possible with schemes in other cantons, which were generally established in 2012-14. The bonus/malus schemes in these two cantons differ in their amounts, and for the fact that malus is retroactive in canton Obwalden, in the sense that it is charged on both new and existing high-emitting cars, but is only applied prospectively to new cars in Geneva.

We analyze a novel, unique, rich dataset obtained through merging multiple sources of information. Our dataset follows individual passenger vehicles over several years. We model the time to retirement of used, fuel-inefficient vehicles. We use survival analysis methods, which take into account the fact that the decision to retire a vehicle depends on its age. Conveniently, the impacts of the policies on the hazard function (the instantaneous likelihood that the vehicle is retired, conditional on its age or ownership time until now) can be converted into the effects on expected age at retirement and/or expected remaining lifetime.

To our knowledge, no previous evaluations of a bonus/malus have focused on the hazard of retirement of used inefficient vehicles. All studies cited so far focus on impacts on the acquisitions, shares or registrations of new vehicles. This is an important gap in the literature because old and inefficient vehicles are usually responsible for a disproportionately larger share of the CO_2 emissions.[8] Vehicles older than six years account for some 60% of the Swiss fleet on the road in a given year and tend to pollute more for each kilometer driven. For instance, in 2005, the average CO_2 emissions rate of vehicles older than six years was 211 g CO_2/km, which is very high compared to the 160 g CO_2/km goal negotiated in 2002 through a voluntary agreement between the Association of Swiss Car Importers and the Federal government (Alberini et al., 2016b).[9]

We evaluate the effects of taxation schemes based on fuel economy or CO_2 emissions rates through a difference-in-difference strategy. Our treated units are *existing* vehicles with the same CO_2 emissions rates as those that are subject to a malus in each of two cantons, Obwalden and Geneva. The malus is retroactive in canton Obwalden, but is only applied prospectively to new cars in Geneva. We seek control units among similar cars in nine cantons with no policy in place in 2013.

To improve the comparability across control and treated vehicles, our models include trim fixed effects. We define a trim as a combination of model-make, body type, engine size, horsepower, fuel type, transmission and number of doors. Because the hazard of retirement is a

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[8] Other studies have examined the impact of gasoline taxes or changes in the price of gasoline on new and used cars, including Bento et al. (2009) and Busse et al. (2013).

[9] The agreement was set in terms of reduction of average fuel consumption from 8.4 liters per 100 kilometers (l/100 km) in 2000 to 6.4 l/100 km by 2008 –a 24% reduction. Using the factors certified by the New European Driving Cycle (see footnote 12), this goal translates to a goal of 160 g CO2/km.

non-linear function of parameters and covariates, our approach is more accurately described as a non-linear difference-in-difference model. Earlier applications can be found in the health economics literature (see Keng and Sheu, 2013; Chang, 2012).

Our results suggest that the retirement of existing high-emitting cars can be hastened *or* postponed by bonus/malus schemes. Focusing on three popular high-emitting models (Toyota Corolla, Toyota RAV, and Hyundai Santamo), we estimate that the bonus/malus has shortened the lifetime of an existing Toyota Corolla by 10.32 months in Obwalden, but extended it by 8.04 months in Geneva. Similarly, the lifetime of a Toyota RAV has been shortened by 9.60 months in Obwalden, and extended by 8.04 months in Geneva. The corresponding figures for a Hyundai Santamo are 6.84 months in Obwalden and 5.04 months in Geneva.

These findings suggest that scrappage of old and highly polluting vehicles can be encouraged through imposing judicious fuel economy or emissions-linked registration fees. Accelerated vehicle retirement (AVR) programs are popular with the public because of the reward received by car owners that retire their vehicles. However, AVR programs have been shown to be an expensive strategy to retire vehicles (Antweiler and Gulati, 2015; Li et al., 2013; Sandler et al., 2012; Dill, 2004). The results in this paper suggest that a bonus/malus program *can* encourage retirement of old and highly polluting cars when these vehicles are subject to the malus, but that its success in doing so depends crucially on whether only new and/or existing vehicles are covered.

The reminder of this paper is organized as follows. Section 2 provides institutional background. Section 3 describes the study design and the econometric methods. Section 4 presents the data and section 5 the results. Section 6 concludes.

2 Institutional background and expected impacts from bonus/malus schemes

Vehicle registration fees that depend on the vehicle's fuel economy or CO_2 emissions were first introduced in Switzerland almost 11 years ago.[10] Canton Vaud implemented a bonus scheme in 2005. By 2013, 14 cantons had implemented either a bonus or a bonus/malus program. That number increased to 16 by 2015, with eight cantons implementing a bonus-only program and the remaining eight a bonus/malus system.

We focus on Geneva and Obwalden for three reasons. First, we wish to cover a period sufficiently long as to allow an appreciable, and measurable, adjustment in the stock of cars. This suggests that we restrict attention to schemes implemented before or in 2009 (but after 2005, the first year for which we have data, which excludes Vaud).

Second, we wish to study programs that contain both a bonus and a malus component because this combination should enhance the attractiveness of replacing high-polluting cars with more efficient ones, making it easier for us to measure such effects. This trims the number of candidate cantons from seven to three--Geneva, Obwalden, and Ticino. Third, to avoid trade of vehicles among cantons as a confounding factor, we rule out cantons with bonus/malus programs that share borders with other cantons with bonus/malus or similar cantons. This criterion means that we drop Ticino, because its neighbors (Graubunden and Vaud) have a bonus policy in place.

Table 1 describes the two bonus/malus schemes studied in this paper. In Obwalden, the malus is applied to vehicles with a fuel energy label G, the worst fuel economy category.[11] In Geneva, the malus is charged on vehicles that emit more than 200 g CO_2/km. The CO_2 emissions

[10] In this paper, the terms "registration tax" or "circulation tax" are used interchangeably. It is understood that these are annual taxes or fees.

[11] Switzerland introduced an energy label for new cars in 2003. The Swiss energy labeling system classifies vehicles in ranges of fuel efficiency based on an indicator that takes into account not only the absolute fuel consumption of a vehicle but also the fuel consumption per 1000 kilograms. This means that the label indicating the best efficiency (the A label) can be attained by small and very efficient vehicles as well by larger and still sufficiently efficient cars (see Alberini et al., 2016a). The efficiency labels range from A (best) to G (worst) (see Alberini et al., 2016).

rate of a vehicle is proportional to the fuel consumption rate of the vehicle, with the proportionality factor differing across diesel and gasoline engines (Sullivan et al., 2004), so this cutoff is equivalent to 8.4 liters/100 km for gasoline cars and 7.5 liters/100 km for diesel cars.[12] Label G vehicles pay a malus of CHF 60 in Obwalden on top of the original registration fee, while in Geneva the original registration tax is increased by 50% for vehicles emitting more than 200 g CO_2/km.

By contrast, fuel-efficient vehicles receive bonuses in both cantons. Bonus-eligible cars are those cars with energy label A or B in Obwalden, and those that emit less than 121 g CO_2/km in Geneva. This is equivalent to 5.1 liters/100 km for gasoline cars and 4.5 liters/100 km for diesel cars. In Obwalden, efficient vehicles receive a bonus equal to 100% of their original circulation tax for the first four years of registration, which means that over that period they are exempted from the circulation tax. In Geneva, efficient vehicles receive a bonus equivalent to 50% of their original circulation tax, which means that they pay only half of the original fee.

Whether the malus applies retroactively plays an essential role in terms of the direction of the effects on the hazard of retirement. The malus in Obwalden is retroactive, and so all used and inefficient vehicles have been subject to it since 2009, regardless of when they were manufactured or purchased. Consequently, we expect used inefficient vehicles to be retired earlier in Obwalden after the malus is imposed because the malus raises the cost of owning one such vehicle. However, the malus is small (only CHF 60 or 8% of the average annual circulation tax), and it is likely that its effect, if any, is that of serving as a signal from the authorities that inefficient vehicles are undesirable. An additional economic incentive to retire used inefficient

[12] In Europe, the emissions rates and fuel economy are certified through the New European Driving Cycle (NEDC), which first captures the combustion gases emitted by the car, including CO_2, and then converts CO_2 emissions rates into the fuel economy using a constant that is specific for each type of fuel. The fuel consumption rate is computed as the CO_2 emissions rate (in grams/kilometer) times 0.0377 for diesel powertrains, and the CO_2 emissions rate in grams per kilometer times 0.0420 for gasoline cars. This is the combined city-highway average fuel consumption rate.

vehicles is the opportunity to be exempted from 100% of the circulation tax if a new, fuel-efficient vehicle is purchased to replace the old one.

The malus in Geneva is not retroactive: It applies only to new purchases. As a consequence, no unambiguous expectations can be formulated on the direction of the effect on retirement of used inefficient vehicles in Geneva. On one hand, the bonus represents an economic incentive to replace used inefficient vehicles with new efficient vehicles. On the other hand, the malus in Geneva may *decrease* the hazard of retirement of used and inefficient vehicles. This would be an instance of the so-called “new source bias” first discussed in Gruenspecht (1982).

If the overall cost of a new vehicle increases due to the malus, individuals who prefer vehicles with relatively high fuel consumption rates may be encouraged to hold on to their old vehicles longer. In this context the cost of a new vehicle is its price, plus fuel costs, plus the annual fixed costs over the lifetime of the car. The Gruenspecht effect has been documented in contexts in which new vehicle prices change due to tighter fuel economy standards (Goulder et al., 2012) and changes in gasoline prices (e.g. Jacobsen and van Benthem, 2015; Li et al., 2009; Bento et al., 2009), and with point sources, such as power plants, whose construction and operation is made more expensive as a result of more stringent air quality regulations. We do not know which of these two effects prevails in Geneva, that from the bonus or the “new source bias” disincentive, as they work in opposite directions. For this reason, we turn to empirical analyses to ascertain the net impact.

3 Econometric model and identification strategy

3.1 Study Design

This paper implements a difference-in-difference design on a survival model of time to retirement of a vehicle. We regard the bonus/malus systems in Obwalden and Geneva as treatments in an experiment, and deploy a difference-in-difference study design to estimate the effect of such policies. We describe our study design in table 2. The treatment is the bonus/malus system. For Obwalden, the treatment group is comprised of high emitters that, in 2009, were aged 4 or older. For Geneva, the treatment group is comprised of high emitters that, in 2010, were aged 5 or older. Both treatment groups are comprised of passenger vehicles that were already registered in 2005, the first year in our dataset, which is well before the policies took place (in 2009 and 2010, respectively).

The control units are passenger vehicles registered in cantons were no policy was in place during our study period (2005-2012). Just like the vehicles in the Obwalden treatment group, the control vehicles were aged 4 or older in 2009, and were registered in the Canton of Uri. The vehicles that serve as controls for the Geneva treatment units were aged 5 or older in 2010, and were registered in one of the 9 cantons where no policy was in place during our study period. We describe below how Uri and these 9 cantons were selected as control cantons.

3.2 Survival analysis

Survival analysis models the time to the occurrence of an event, and the factors associated with such time (Cleves et al., 2010). A key concept in survival analysis is the hazard function, namely the density of time to retirement, conditional on that fact that duration has lasted a specified length of time (Bhat and Pinjari, 2000). Formally, let T be a non-negative random variable representing duration (i.e., lifetime) of an individual or unit. The description below assumes that T is continuous and omits the individual car subscript for the sake of simplicity.

The hazard at time u on the continuous-time scale, $\lambda(u)$, is defined as the probability that duration ends in an infinitesimally small time period h after time u, given that duration has lasted until time u, i.e.

$$\lambda(u) = \lim_{h \to 0^+} \frac{\Pr(u \le T < u + h \,|\, T > u)}{h} \tag{1}$$

Clearly, by definition the hazard function depends on both the density function $f(.)$ and the cumulative distribution function $F(.)$ of T. Since the probability of duration terminating in an infinitesimally small time period h after time u is $f(u)*h$, and the probability that the duration is longer than u is $1\text{-}F(u)$, the hazard rate can be written as

$$\lambda(u) = \frac{f(u)}{[1 - F(u)]} = \frac{f(u)}{S(u)} = \frac{dF/du}{S(u)} = \frac{-dS/du}{S(u)} = \frac{-d\ln S(u)}{du}, \tag{2}$$

where $S(u)$ is the probability that duration did not end prior to u, i.e., the survival function.

The hazard function can be written as a function of covariates ($\mathbf{X}$):

$$\lambda(u, X) = g(u, \beta_0 + \mathbf{X}\beta_x) \tag{3}$$

In this paper, we assume that T follows a Weibull distribution, so that

$$\lambda(u, X) = \alpha u^{\alpha-1} \exp(\mathbf{X\beta}) = \alpha u^{\alpha-1} \theta_i \tag{4}$$

The shape parameter (α) defines whether the hazard rate rises monotonically with time (α>1), falls monotonically with time (α<1), or is constant (α=1), in which case the Weibull is simplified to an exponential distribution. We use a Weibull distribution to take advantage of the flexibility provided by its shape parameter.

Equation (4) describes a Weibull proportional hazard (PH) model. PH models satisfy a separability assumption, namely that

$$\lambda(u,\mathbf{X}) = \lambda_0(u)\theta, \tag{5}$$

where $\lambda_0(u)$ is the baseline hazard function which depends on time but not on covariates. Parameter $\theta_i = \exp(\mathbf{X\beta})$ is vehicle-specific, non-negative, and depends on covariates but does not depend on time. In other words, θ scales $\lambda_0(u)$ up or down. Thus the hazard of a particular vehicle at time *u* is calculated by substituting the corresponding covariates values into θ, and then multiplying θ times $\lambda_0(u)$. Even holding the current lifetime of the vehicle the same, vehicles with different characteristics will have different hazards.

Usually, one is interested is the impact of a specific covariate on the hazard rate. The feature of proportionality turns is convenient when the focus is on the impact of a dichotomous variable, for instance if vehicle is subject to a malus after a certain year. The proportional hazard property implies that the impact from a dichotomous variable can be evaluated by comparing the hazard rates with the dichotomous variable set to one and then set to zero.

Denote as β_m the regressor coefficient on the dichotomous variable *m*. Two identical vehicles (in terms of observable covariates and time elapsed) differing only for the value of *m* can be compared by comparing their hazard rates to form the hazard ratio:

$$\frac{\lambda(\bar{u}, m=1)}{\lambda(\bar{u}, m=0)} = \exp(\beta_m) \tag{6}$$

The right-hand side of equation (6) is interpreted as the proportionate change in the hazard rate given a change in a dichotomous variable with all other covariates held fixed. If $\exp(\beta_m) = 1$, then the dichotomous variable introduces no change in the hazard rate: $\lambda(\bar{u}, m=1)$

$= \lambda(\bar{u}, m = 0)$. If $\exp(\beta_m) = 1.05$, then setting the dichotomous covariate to 1 increases the hazard rate by 5%, whereas it decreases it by 5% if $\exp(\beta_m) = 0.95$.

3.3 Difference-in-difference within a survival model

The proportional Weibull hazard model yields the impact from covariates on the instantaneous probability of retirement. We are interested in assessing the effect of a treatment, and have data from before and after the treatment for treated and control units. This suggests the following difference-in-difference hazard function:

$$\lambda(u, \boldsymbol{X}) = \alpha u^{\alpha-1}\exp(\beta_0 + \beta_D D + \beta_M M + \beta_{DM} DM + \beta_{trim} trim + \boldsymbol{X}\beta_x), \qquad (7)$$

where M is a dummy indicating the treatment group, D denotes the treatment period, and DM=D*M, meaning that the treatment is in place for this particular unit. Variable *trim* is a categorical variable identifying vehicles by their model-make, body type, engine size, horsepower, fuel type, transmission and number of doors. Row vector **X** includes additional control variables such as age of the vehicle in 2005, and characteristics of the municipality where it is registered.

Notice that we are expressing the treatment effect on the treated in terms of the hazard function, not in terms of a measured outcome variable and its expected value as in much empirical difference-in-difference work (see Card and Krueger, 1994; Khandker et al., 2010). Moreover, equation (7) implies that the sign of β_{DM} indicates the direction of the treatment effect on the treated, but the value of this coefficient in itself is not the magnitude of the treatment effect, either on the hazard or the expected lifetime of a car (Puhani, 2012). Thus,

$$\begin{aligned}\tau(D=1, M=1, \boldsymbol{X}, trim) \\ &= \lambda^1(D=1, M=1, u, trim, \boldsymbol{X}) - \lambda^0(D=1, M=1, u, trim, \boldsymbol{X}) \\ &= \alpha u^{\alpha-1}\exp(\beta_0 + \beta_D + \beta_M + \beta_{DM} + \beta_{trim} trim + \boldsymbol{X}\boldsymbol{\beta}_x) \\ &- \alpha u^{\alpha-1}\exp(\beta_0 + \beta_D + \beta_M + \beta_{trim} trim + \boldsymbol{X}\boldsymbol{\beta}_x)\end{aligned} \quad (8)$$

where $\tau(.)$ is the treatment effect of interest. This effect is defined as the hazard function of a treated unit (λ^1) minus the potential hazard function of that unit in the non-treated state (λ^0), had that treated unit not been treated (see Puhani, 2012). Since τ is a difference of instantaneous probabilities or hazards, the units for τ, the treatment effect on the treated, are instantaneous probabilities or hazards.

We wish to emphasize that the hazard function is estimated from the vehicle registration data and through parametric assumptions, and not measured directly as in much applied work that relies on a difference-in-difference design. The treatment effect in (8) is thus computed after plugging the estimated coefficients and covariates into the hazard function. The treatment affects the hazard function, and is different for different vehicles, depending on the values of the covariates for that vehicle and the *u* for which the calculations are made.

3.4 Likelihood function

Our dataset tells us whether each vehicle was retired (i.e., not re-registered) from one year to the next, or was not retired (i.e., still registered) by the time our study period ends. The latter feature is termed right censoring and arises from the fact that not all vehicles have completed their lifetime during our study period.

In our sample, all of the observations that are not right-censored are in interval-data format. We know the date of first registration of the car, say May 3, 2005. We also know whether the car is still registered by the administrative cutoff date of each year (October 31). Say that a car is still registered as of October 31, 2010. Then the "age" of the car as of October 31, 2010 is the number of days between these two dates, namely 2007. If the car is not present in the list of registered cars as of October 31, 2011, then we conclude that it must have been retired between age 2007 and age 2372 days. In other words, retirement must have occurred anytime between the last time we are able to verify their registration, at age u_i^{lower}, and the administrative cut-off date of the subsequent year, at age u_i^{upper}.

Under the assumption that the lifetime of a vehicle (T_i) follows a Weibull distribution, the corresponding hazard function $\lambda(u)$ is presented in equation (4) and the survival function is $S(u)$ =exp($\theta_i u^{\alpha}$). The log-likelihood function of our data is thus:

$$log\mathcal{L} = \sum_{i=1}^{N} \left\{ c_i \log\left[F\left(u_i^{upper}\right) - F\left(u_i^{lower}\right)\right] + (1 - c_i) logS(u_i) \right\} \tag{9}$$

where c_i is an indicator for right-censoring that takes on a value of one if vehicle *i* has completed its spell, and zero otherwise. The contribution to the likelihood is thus the probability that retirement occurred in between the lower and upper age of a car if a car was retired, and the survival function evaluated at the age of the vehicle at the end of our study period if the car was not retired.

In practice, as we explain in section 4 below, we have limited information about the fate of a car that was retired from a canton's fleet of registered vehicles. For this reason, we define as a "retirement" from a canton any instance when a car is not re-registered in that canton.

4 Data

4.1 Sources of Data

The dataset analyzed in this paper was created through merging records from three sources. Data on passenger vehicles registered in Switzerland come from the Swiss Federal Roads Office (FEDRO). Socioeconomic data at the municipality level are reported by the Swiss Federal Statistics Office (SFSO). Information on the specifics of the bonus/malus schemes is obtained from the cantonal vehicle tax regulations. A thorough description of the merging process, including validity checks, is reported by Alberini et al. (2016b).

The dataset covers passenger vehicle registrations from 2005 to 2013. For each vehicle circulating in Switzerland those years, we have the make-model, trim and variant, body type, engine size, horsepower, fuel type, transmission, number of doors, fuel economy and CO_2 emissions rate. Our dataset does not contain any information about the socioeconomic circumstances and driving habits of the owner of the vehicle. To circumvent this limitation, we append information on the sociodemographic conditions and geography of the municipality of residence of the owner.

4.2 Definition of retirement

Our data contains extensive information about each vehicle, but not the identity of the owner. All we know is the canton of registration and the zip code of residence of the owner. If a car is re-registered and the zip code is the same, it is not possible for us to know whether the original owner still has it or simply sold it to someone else that lives in the same municipality. If a car is registered at a different zip code within the same canton, we do not know if it was sold to someone else or if it stayed with the original owner who simply moved to a different home. For the purposes of this paper, we regard these two examples as situations in which the car is still "alive" within the original canton and has not been retired.

In some cases a car is not re-registered in the original canton, but is registered in another canton. We can track these situations, and regard them as retirements (from the canton of first registration), even though the car is still in use elsewhere. In other cases yet, a car is no longer registered in the canton of first registration, and does not reappear in any other canton in Switzerland, so we do not know whether the car was taken to a junkyard or sold or moved to a different country. We regard these latter cases as retirements. Our goal is to see whether bonus/malus programs at the cantonal level were effective at discouraging the re-registration of inefficient vehicles in the canton where the policy is in place.

4.3 Definition of treated and control units

This study seeks for an impact from a bonus/malus program on two distinct populations of vehicles. One is the set of used and fuel-inefficient vehicles registered in Obwalden as of 2005 (label G vehicles, vintages 1996 to 2004). The other is the set of used and fuel-inefficient vehicles registered in Geneva as of 2005 (vehicles emitting more than 200 g CO_2/km, vintage 1996 to 2004). We remind the reader that, due to the perfect relationship between CO_2 emissions rates and fuel consumption rates, these are gasoline vehicles that use more than 7.5 liters/100 km and diesel vehicles that use more than 8.4 liters/100 km. These two groups of vehicles are treated with a malus at the cantonal level. In Obwalden, treatment initiates in 2009. In Geneva, treatment starts in 2010.

A clarification is in order. Treatment in this paper is the introduction of the bonus/malus program in Obwalden and Geneva. Neither treated group is an actual beneficiary of the bonus component of the program. Moreover, only used and inefficient vehicles in Obwalden are directly "penalized" with a malus. The used and inefficient vehicles in Geneva are *not* directly affected by the malus, because the malus is only applied to new inefficient vehicles. However, we are interested in them because we are seeking evidence of an indirect effect arising from the interaction between the market of used and inefficient vehicles and the new car market (see section 2).

Control vehicles of age similar to the age of the treated vehicles were sought in 9 cantons that kept their vehicle registration fees and system unchanged between 2005 and 2013. These cantons are Aargau, Jura, Luzern, Neuchatel, Schaffhausen, Solothurn, Schwyz, Uri, and Zug. We selected our control units, which are individual vehicles, so as to match them as closely as possible with the make-model-trim-variants in a treated canton. (Recall that a make-model-trim-variant is a combination of make, model, body type, engine size, horsepower, fuel type, transmission and number of doors. Consider for example a 1999 Toyota 1800 4x4, one of the most popular "treated" vehicles in Obwalden in 2005. The trim-variant of this vehicle is unique, in that horsepower is 108.6,[13] transmission is manual, there are four doors and this car runs on gasoline. The corresponding control vehicle is a 1999 Toyota 1800 4x4 with exactly the same features but registered in the corresponding control canton(s).

4.4 Selection of control cantons

While control vehicles are comparable to treated vehicles based on their trim, cantonal characteristics may influence the comparisons. For instance, assume that the control vehicles are registered in a canton where the percentage of used and inefficient vehicles is systematically lower than in the rest of Switzerland. This difference may reflect that the residents of the control

[13] In our dataset, horsepower is measured in kilowatt (kW). One horsepower is equivalent to 0.7457 kW.

canton are somehow more likely to buy efficient vehicles and may signal systematic differences in retirement rates across cantons.

Thus, we implement a strategy to find cantons whose vehicle fleet composition resembles as closely as possible the vehicle fleet of each treated canton. As a first step in this search strategy, we check that the trade of used inefficient vehicles among potential control cantons and treated cantons is negligible, so that it can be disregarded as a potential confounding factor. Tables 3 and 4 report the percentage of used and inefficient vehicles registered in treated cantons in a given year that were subsequently registered in the treated cantons or in one of the 9 potential control cantons.

Table 3 presents figures for Obwalden. The first column of table 3 reports the percentage of label G vehicles in Obwalden in a given year that were registered in Obwalden the subsequent year. Until 2010, the percentage of label G vehicles re-registering in Obwalden fluctuates around 84%[14]. Starting in 2011, there is a declining tendency from 81.74% to 75.46%, indicating a slightly faster retirement rate.

Table 3 documents low trade rates among Obwalden and the 9 potential control cantons. In a given year, the potential control cantons receive between a total of 2.5% to 3% of label G vehicles that were registered in Obwalden in the previous year. Neuchatel is the canton receiving the most label G vehicles from Obwalden, with percentages ranging from 1.17% to 1.92%. Aargau, and Jura have nearly received no vehicles from Obwalden in the period 2006 to 2013.

Table 4 presents the figures for Geneva. In the first column, we can see that, in comparison to Obwalden, a larger proportion of used inefficient vehicles re-register in Geneva in a given year.

[14] The share of G labelled cars is so high because the energy label applies to new cars only and was revised every other year until 2011, and every year since. Because of the biennial revisions, older cars tend to be reassigned to a worse category, making their shares very high.

The percentage of re-registrations fluctuates around 95% from 2006 to 2010. The re-registration rate in 2011-2013 is around 94.5%--a negligible change with respect to the pre-2011 rates.

Table 4 shows that the 9 potential control cantons receive few vehicles from Geneva, with percentages ranging between 0.60% and 0.70%. Neuchatel is the canton receiving the largest percentages of used vehicles emitting more than 200 g CO_2/km from Geneva, with percentages fluctuating between 0.14% and 0.22%.Thus, based on the figures in tables 3 and 4, it seems reasonable to conclude that inefficient vehicles retiring from treated cantons do not usually end up in one of the 9 potential control cantons.

Next—our second step in the search for adequate control cantons—we carry out a matching exercise at the cantonal level. We use the Coarsened Exact Matching (CEM) algorithm on variables that describe the vehicle fleet composition in 2005 at the cantonal level (see Iacus et al., 2011, for details on the CEM). The matching variables summarize the distribution of vintages, CO_2 emissions, fuel efficiency labels, fuel types, and vehicle weight in each canton. For each treated canton, the CEM algorithm seeks control cantons with identical values of the matching variables as the treated canton. When a matching variable is continuous, the algorithm discretizes it.[15]

Appendix A reports the percentage of vehicles falling into each category of these variables. Table A.1 reports the percentage of vehicles by vintage (before 1990, 1991-1995, 1996-2000, and 2001-2005). Table A.2 reports the percentage of vehicles in each canton by range of CO_2

[15] We wish to emphasize that this is an informal application of the CEM, which we use for exploratory purposes. CEM is most often deployed to estimate the average effect of a treatment when the treated and control units are potentially unbalanced with respect to a set of covariates. CEM trims the sample of any unmatched units, and computes weights based on the overall sample counts of treated and control units, and on the counts in the stratum (a given combination of values of the matching variables) where a unit belongs to. Finally, the average treatment effect is estimated by running a regression of the outcome variable on the treatment indicator and on the matching variables (which are entered in the regression to eliminate any remaining unbalance). The regression deploys weighted least squares, the weight being the CEM weights described above. See Alberini and Towe (2015) for an application of CEM when assessing the effect of a an energy-efficiency upgrade on household residential energy consumption.

emissions rates (less than 150 g/km, 150-199 g/km, 200 and more g/km). Table A.3 reports the percentage of vehicles by each of the seven fuel efficiency labels (A to G). Table A.4 reports the percentage of vehicles by fuel and range of total weight in tons.

Table 5 presents the result of the matching process. Each column of table 5 reports the resulting match given a set of variables used in the matching algorithm. We first experimented with a single matching variable, and then attempted matching with respect to two, and three, matching variables. For each column, the cross identifies the matched cantons. The first column shows that, if only the distribution of vintages is used as the basis for matching, Obwalden can be matched with Solothurn and Uri. The second column indicates that, if matching is done only with respect to CO_2 emissions rates, Obwalden can be matched to Aargau, Schaffhausen, Schwyz, and Uri. No matches are found when matching is done with respect to the shares of the various energy labels.

Based solely on fuel, Geneva and Obwalden can be matched with Luzern, Solothurn, and Zug. When based on weight alone, Obwalden can be matched with Neuchatel and Uri. When using both vintage and CO_2 emissions, Obwalden can be matched with Solothurn and Uri. However, no matches among candidate control cantons are found for Geneva when using i) vintages, ii) CO_2 emissions, or iii) label (or vintage), CO_2 emissions, and fuel. Finally, based on vintage, CO_2 emissions, and weight Obwalden can be matched with Uri.

From table 5, we conclude that Uri is probably the “best” control canton for Obwalden. Uri is the only canton that is comparable to Obwalden when using three variables in the matching process and is comparable to Obwalden in four of the six single-variable matching processes. In contrast, with the only exception of the variable fuel, it is difficult to find unambiguous, high-quality matches for Geneva among the individual candidate control cantons. Based on his evidence, we proceed as follows. We use all 9 cantons as control cantons for Geneva, plus Solothurn and Uri individually, as controls to check the robustness of the direction of the impact.

5 Results

We fit likelihood function (9) based on the Weibull proportional hazard to model the lifetime of a vehicle In this paper, retirement occurs if a vehicle is registered in year t but not in year (t+1). We remind the reader that, as shown in equation (9), we account for right censoring and the interval nature of our data, and that in this paper a car is considered retired when it is no longer re-registered in the canton, regardless of its fate.

Our proportional hazard models include several covariates, including make-model-trim effects. We further include the age of the vehicle in 2005 to capture cohort effects related to technology, consumer taste, and other factors. We have no information about owner characteristics, and driving habits or specific geographical conditions or weather in which the vehicle is driven. To control to some extent for these unobserved conditions, we include average distance to the nearest city and central measures of the elevation at each municipality among our covariates.

Tables 6 and 7 report the results from five alternate specifications. Specification (I) models retirement as a function of time-invariant variables, such as vehicle age in 2005, the log of average distance from the municipality where the car owner resides to the closest city, and the log of the median altitude in the municipality. Specification (II) adds to (I) a dummy that identifies the treated canton. Specification (III) adds to (I) a dummy that captures the post-policy period. Specification (IV) adds to (I) a dummy that identifies the treated canton and a dummy that captures the post-policy period. Specification (V) further adds a dummy associated with the treatment effect, i.e. a dummy resulting from the interaction between the post-policy period and the treated canton dummies. Clearly, specification (V) is the one that establishes whether there is a treatment effect.

Table 6 reports results for Obwalden (treated canton) when compared to Uri (control canton). Model (I) indicates that the older the vehicle in 2005, the higher its hazard of retirement in a given year—around 11% increase each year.

The distance to the closest city is associated with a higher hazard of retirement. This variable partially captures driving habits. If larger distance to the closest city is associated with higher odometer readings, then the positive association between distance and hazard of retirement makes intuitive sense. Model (I) yields a shape parameter of 1.78 which implies that the hazard rate rises monotonically with time. This is intuitive as older vehicles are expected to retire at higher rates than younger ones.

The estimates from model (I) do not substantially change when the dummy identifying Obwalden is added as in model (II). The fact that the coefficient on the Obwalden dummy is insignificant suggests that Obwalden and Uri have similar retirement patterns to begin with. Model (III) shows that the hazard of retirement in the post-policy period is around 66% smaller than in the pre-policy period. This post-policy period dummy takes a value of one if year of observation is 2009 or later. The negative coefficient on this variable means that people hold on to their cars longer, and is thus consistent with the pattern depicted by figure 1, where new car registrations in Switzerland decrease in 2008, reaching a minimum in 2009, suggesting that, all else the same, the Swiss must be keeping their vehicles longer.

Specification (IV) in table 6 adds to (I) both post-policy and Obwalden dummies. The coefficient on the Obwalden dummy becomes significant, but the rest of the results are very similar to their counterparts from the previous specifications. Model (V) adds the treatment effect variable to model (IV). The parameter associated with the treatment effect is positive (0.513) and statistically significant, implying that the bonus/malus policy in Obwalden has *increased* the hazard of retirement of used and inefficient (label G) vehicles in Obwalden. This is as expected, because the bonus/malus in Obwalden simultaneously signals that old inefficient vehicles are undesirable and incentivizes the purchase of new efficient vehicles. We summarize below the magnitude of this effect.

Table 7 reports results for Geneva when compared to all 9 control cantons. Model (1) in table 7 tells a similar story as model (I) in table 6: an older vehicle faces a higher hazard of retirement and the shape parameter indicates that the hazard rises monotonically with time. Specification (II) indicates that used inefficient vehicles face a systematically smaller hazard of retirement in Geneva than their counterparts in control cantons. Model (III) shows that the hazard of retirement during the post-policy period is smaller than that in the pre-policy period. This result is similar to that reported in Table 6 for Obwalden. Finally, specification (IV) shows that the magnitudes and signs of all of these effects are very similar when we further include the post-policy and the Geneva dummies.

The most striking result in table 7 is that from model (V), which shows that the treatment effect of the bonus/malus in Geneva is negative: The hazard of retirement of used and inefficient vehicles *decreases* due to the bonus/malus policy. As discussed in section 2, the effect of the bonus/malus in Geneva cannot be signed unambiguously through theory. Our empirical results indicate that it is negative, which means that the introduction of the malus reduces the hazard of retirement and extends the remaining lifetime of old and inefficient vehicles This suggests the presence of a “Gruenspecht-like” effect.

We conduct robustness checks and report them in appendix B. Tables B.1 shows that when Solothurn is the control canton, the treatment effect is qualitatively similar as in the analyses of table 7. Table B.2 where Uri is the control canton and Geneva the treatment canton displays similar results.

The impacts on the hazard of retirement are visually displayed in figures 2 and 3. Figure 2 depicts the estimated hazard rate of retirement of a vehicle that is assumed to be six years old in 2005. This hazard rate is estimated using the parameter estimates from specification (V) in table 6. Two sets of hazard rates are depicted. The solid line is the hazard rate of a vehicle registered in Obwalden from 2006 to 2013. The dashed line represents the hazard rate of an identical vehicle registered in a counterfactual Obwalden without the policy. As shown in equation (8), the counterfactual Obwalden is estimated by omitting the treatment effect parameter from the calculation of the hazard rate of retirement. The treatment effect is the difference in the hazard rate between the treated and counterfactual Obwalden.

Two striking results are easily seen in figure 2 that are implied by specification (V) in table 6. The first is the sharp drop in the hazard of retirement in 2009. The post treatment variable captures this drop in both cantons, leading us to conclude that it is likely a nationwide trend. The second is the difference between the hazard of retirement in the treated and the counterfactual Obwalden. The counterfactual Obwalden suggests that vehicles in Obwalden are retired faster when the policy is in place than they would be otherwise.

Figure 3 depicts two hazard rate patterns from specification (v) in table 7 to illustrate the effects of the bonus/malus policy in Geneva. The solid line is the hazard of a vehicle registered from 2006 to 2013 in Geneva. The dashed line is the hazard for the same vehicle registered in a counterfactual Geneva without the policy. Figure 3 differs from figure 2 in that the hazard of retirement is higher in the counterfactual scenario: Used and inefficient vehicles in Geneva face a lower hazard when the policy is in place, implying that they are retired later than in the absence of the policy.

Another way to summarize the impacts from the policies is to compute the age at retirement for the treated canton and its counterfactual without treatment. Table 8 reports the median age to retirement of three vehicles that are assumed to be aged 6 in 2005. These vehicles were the three most common vehicles in Obwalden in 2005, namely a Toyota Corolla, a Toyota RAV, and a Hyundai Santamo. The counterfactual Toyota Corolla would have "lived" 10.67 years; its treated version 9.80 years. In other words, the Toyota Corolla would be retired 0.86 years, or 10.32 months, earlier due to the policy. This difference in age at retirement is statistically different from zero at the conventional levels. With the Toyota RAV, the difference in age at retirement is 0.80 years, or 9.60 months. The Hyundai Santamo illustrates that the effects are very heterogeneous across vehicles: the effect of the malus/bonus policy in Obwalden is a 6.84-month difference in remaining lifetime–from 9.11 years to 8.52 years.

In Geneva, the counterfactual Toyota Corolla would have been registered for a total of 10.35 years; its treated version 11.03 years. In contrast to Obwalden, the retirement of a Toyota Corolla in Geneva is postponed by 8.04 months as a consequence of the malus/bonus scheme. The model predicts an effect of similar magnitude for a Toyota RAV in Geneva. With the Hyundai Santamo, retirement is postponed by 5.04 months. These calculations show that a malus scheme expected to discourage people from buying highly polluting cars (see Alberini and Bareit, 2016) can be counterproductive in the sense that it can encourage people to hold on to their existing high-emitter. The effect on the age of the vehicles at retirement varies across cars.

A back-of-the-envelope calculation indicates that, for instance, a Toyota Corolla with gasoline powertrain in Geneva would have generated 1.60 tons of CO_2 emissions in such additional lifetime, assuming that its owner had driving habits similar to those of the average driver.[16] This figure is the product of the emissions rate (224 g/km) times 10,726 km times 8.04/12 months. Had the car being replaced by a low-emitter during that period (e.g., a vehicle with emissions rate of 120 g/km), under similar assumptions about the distance driven the total emissions would have been only 0.863 tons of CO_2.

6 Discussion and Conclusions

The results in this paper suggest that a bonus/malus scheme imposed on new and/or existing cars affects the expected age at retirement of existing high-emitting, fuel-inefficient cars, and thus its effects are not limited to the new car sales. The direction of the effect, however, depends crucially on whether the scheme applies to new cars only.

Specifically, we find that the retirement of existing high-emitting, fuel-inefficient cars is postponed in Geneva, a Swiss canton in which the malus component applies only to new high-emitting, fuel-inefficient cars. This effect is undesirable because the goal of a bonus/malus scheme is to encourage car owners to buy and use efficient cars, and is akin to a "new source bias" much like the one first discussed in Gruenspecht (1982). The Gruenspecht effect has been documented in different contexts by Goulder et al. (2012), Jacobsen and van Benthem (2015), Li et al. (2009), and Bento et al. (2009).

[16] Using the Swiss Mikrozensus Mobilität und Verkehr from 2010, we estimate that gasoline cars are driven on average 10,726 kilometers a year, whereas diesel cars are driven on average 15,348 kilometers a year. The vehicle kilometers traveled (VKT) decline only very slowly with the age of the car. The VKT is described by the regression equation VKT=12,46.27-193.07*age (in years) for gasoline cars and VKT=17,114.43-330.03*age for diesel cars.

In contrast to Geneva, the bonus/malus scheme in Obwalden accelerates the retirement of existing high-emitting, fuel-inefficient cars. Two factors are likely behind the different direction of the effects. First, existing vehicles in Obwalden are subject to the malus component of the bonus/malus scheme. Although the "penalty" for driving an inefficient car is small (60 Swiss francs annually), there is at least the signal that inefficient cars are undesirable. Using stated preference techniques, Hilton et al. (2014) show that a bonus/malus has a social norm effect arising from implicitly classifying the less polluting option as pro-social and the polluting option as antisocial. The second factor may lie in the criteria that define inefficient vehicles in Obwalden. The definition is based on the Swiss energy efficiency label, and so there is the possibility of substituting between efficient and inefficient vehicles that belong to a similar segment of the car market. To further elaborate on this, suppose a household has strong preferences for sport utility vehicles (SUVs). The energy label system in Switzerland makes it possible to find relatively efficient vehicles even among SUVs.

A caveat is in order. Survival analysis is sometimes deployed in the transportation literature to identify the determinants of scrappage (see Anovar et al., 2014; Chen and Niemeier, 2005). This literature usually estimates competing risk survival models in order to account for different reasons behind scrappage decisions (e.g. Yamamoto et al., 2004). Variables reflecting competing risks are not observed in our dataset. Moreover, we do not know exactly what the fate of a retired vehicle is—was it taken to a junkyard or sold, or the owner moved to another canton? This limitation is shared by other applications studying vehicle retirement (e.g. Jacobsen and van Benthem, 2015).[17]

[17] Due to this data limitation, the retirement rate measure used in this paper can be more precisely describe as "the change in legally registered Swiss fleet," following Jacobsen and van Benthem (2015) who face a similar problem with their data from the U.S.

Because of our focus on the retirement of used, high-emitting vehicles, this paper is related to the literature evaluating accelerated vehicle retirement programs. These programs aim to encourage retirement of old, inefficient vehicles by buying back eligible vehicles or by offering rebates to individuals trading in an old vehicle and purchasing a new one.[18] However, they are not the most cost effective strategy to retire high emitting cars because they attract car owners that would have retired their vehicles even in the absence of the program (Li et al., 2013; Sandler, 2012; Dill, 2004; Alberini et al., 1996, 1995). The results from our paper suggest that retirement of old cars can be reached through a bonus/malus scheme as well. Indeed, our results show that care is necessary when designing such programs: a bonus/malus that does not takes the entire stock of vehicles into account may have the unintended and adverse consequence of extending the lifetime of old and inefficient vehicles. This may be especially important to bear in mind in countries where these programs can be established independently by different jurisdictions (such as the states, provinces or cantons), where one jurisdiction may create incentives attracting vehicles from other jurisdictions and thus compromise the goals of the program.

[18] Evaluations of recent scrappage programs include Cantos-Sánchez et al. (2015) in Spain, and Li et al. (2013) for the U.S.

REFERENCES

Adamou, A., Clerides, S. and Zachariadis, T. (2012). "Trade-offs in CO 2-oriented vehicle tax reforms: A case study of Greece." Transportation Research Part D: Transport and Environment 17(6): 451-456.

Adamou, A., Clerides, S., and Zachariadis, T. (2014). "Welfare Implications of Car Feebates: A Simulation Analysis." The Economic Journal 124(578): F420-F443.

Alberini, Anna, and Markus Bareit (2016). "The effect of registration taxes on new car sales and emissions: Evidence from Switzerland." CER-ETH Economics Working Paper 16/245. Available at https://www.ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/cer-eth-dam/documents/working-papers/WP-16-245.pdf

Alberini, Anna, Winston Harrington, and Virginia McConnell (1995). "Determinants of participation in accelerated vehicle-retirement programs." The RAND Journal of Economics 26(1): 93-112

Alberini, Anna, Winston Harrington, and Virginia McConnell (1996). "Estimating an emissions supply function from accelerated vehicle retirement programs." The Review of Economics and Statistics 78(2): 251-265.

Alberini, Anna, and Charles Towe (2015). "Information v. energy efficiency incentives: Evidence from residential electricity consumption in Maryland." Energy Economics 52: S30-S40.

Alberini, Anna, Markus Bareit, and Massimo Filippini (2016a). "Does the Swiss Car Market Reward Fuel Efficient Cars? Evidence from Hedonic Pricing Regressions, Matching and a Regression Discontinuity Design." The Energy Journal 37 (3): 315 – 342.

Alberini, Anna, Markus Bareit, and Massimo Filippini (2016b). "Economic analysis of policy measures to reduce CO_2 emissions of passenger cars in Switzerland." Report for the Swiss Federal Office for the Environment (FOEN) and the Swiss Federal Roads Office (FEDRO), Bern. Available at http://www.bafu.admin.ch/klima/00509/13883/index.html?lang=de&download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1acy4Zn4Z2qZpnO2Yuq2Z6gpJCHen58e2ym162epYbg2c_JjKbNoKSn6A--

Anderson, S. T., Parry, I. W., Sallee, J. M., and Fischer, C. (2011). “Automobile fuel economy standards: Impacts, efficiency, and alternatives.” Review of Environmental Economics and Policy, doi: 10.1093/reep/req021.

Anovar, Sabreena, Naveen Eluru, and Luis F. Miranda-Moreno (2014). "Alternative Modeling Approaches Used for Examining Automobile Ownership: A Comprehensive Review." Transport Reviews 34(4): 441-473.

Antweiler, Werner, and Sumeet Gulati (2015). “Scrapping for clean air: Emissions savings from the BC SCRAP-IT program.” Journal of Environmental Economics and Management 71: 198-214.

Bento, Antonio M., Lawrence H. Goulder, Mark R. Jacobsen, and Roger H. Von Haefen (2009). "Distributional and efficiency impacts of increased US gasoline taxes." The American Economic Review 99(3): 667-699.

Bento, Antonio M., Kevin D. Roth, and Yiou Zuo (2013). "Vehicle Lifetime Trends and Scrappage Behavior in the US Used Car Market." Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2262593.

Bhat, Chandra R., and A. R. Pinjari (2000). "Duration modeling." Handbook of transport modelling 6: 91-111.

Busse, M.R., Knittel, C.R. and Zettelmeyer, F. (2013). “Are consumers myopic? Evidence from new and used car purchases.” The American Economic Review 103(1): 220-256.

Cantos-Sánchez, Pedro, Eva Gutiérrez-i-Puigarnau, and Ismir Mulalic (2015). "The impact of scrappage programs on the demand for new vehicles: Evidence from Spain." Available at http://mpra.ub.uni-muenchen.de/61224/1/MPRA_paper_61224.pdf.

Card, David, and Alan B. Krueger (1994). “Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania.” American Economic Review 84(4): 772-793.

Cerruti, Davide, Anna Alberini, and Joshua Linn (2016). "Charging Drivers by the Pound: The Effect of the VED System in the UK", Mimeo.

Chang, S. (2012). The effect of Taiwan's National Health Insurance on mortality of the elderly: revisited. Health economics 21(11): 1257-1270.

Chen, Cynthia, and Debbie Niemeier (2005). "A mass point vehicle scrappage model." Transportation Research Part B: Methodological 39(5): 401-415.

Ciccone, A. (2015). Is it all about CO_2 emissions? The environmental effects of a tax reform for new vehicles in Norway (No. 19/2014). Memorandum, Department of Economics, University of Oslo. Available at http://www.econstor.eu/handle/10419/102057

Cleves, Mario, William Gould, Roberto Gutierrez, and Yulia Marchenko (2010). "An Introduction to Survival Analysis Using Stata." Stata Press.

D'Haultfoeuille, Xavier, Pauline Givord, and Xavier Boutin (2014). "The environmental effect of green taxation: the case of the French bonus/malus." The Economic Journal 124: F444-F480.

Dill, Jennifer (2004). “Estimating emissions reductions from accelerated vehicle retirement programs.” Transportation Research Part D 9: 87-106.

Gillingham, Kenneth (2013). "The economics of fuel economy standards versus feebates." Mimeo. Available at http://www.yale.edu/gillingham/Gillingham_FeebatesCAFE.pdf

Goulder, L. H., Jacobsen, M. R., & Van Benthem, A. A. (2012), “Unintended consequences from nested state and federal regulations: The case of the Pavley greenhouse-gas-per-mile limits.” Journal of Environmental Economics and Management 63(2): 187-207.

Greene, David L., Philip D. Patterson, Margaret Singh, and Jia Li (2005). "Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy." Energy Policy 33 (6): 757-775.

Gruenspecht, Howard K. (1982), “Differentiated regulation: The case of auto emissions standards.” The American Economic Review 72 (2): 328-331.

Hilton, Denis, Laetitia Charalambides, Christophe Demarque, Laurent Waroquier, and Charles Raux (2014). "A tax can nudge: The impact of an environmentally motivated bonus/malus fiscal system on transport preferences." Journal of Economic Psychology 42: 17-27.

Huse, Cristian, and Claudio Lucinda (2014). "The market impact and the cost of environmental policy: evidence from the Swedish green car rebate." The Economic Journal 124(578): F393-F419.

Iacus, Stefano M., Gary King, and Giuseppe Porro (2011). "Causal inference without balance checking: Coarsened exact matching." Political Analysis, doi: 10.1093/pan/mpr013

International Council of Clean Transportation (ICCT, 2013). European Vehicle Market Statistics – Pocketbook. Available at http://eupocketbook.theicct.org/

Jacobsen, Mark R., and Arthur A. Van Benthem (2015). "Vehicle scrappage and gasoline policy." American Economic Review 105(3): 1312-1338.

Keng, S.H. and Sheu, S.J. (2013). The effect of national health insurance on mortality and the SES–health gradient: evidence from the elderly in Taiwan. Health economics, 22(1): 52-72.

Khandker, S.R., Koolwal, G.B. and Samad, H.A., (2010). Handbook on impact evaluation: quantitative methods and practices. World Bank Publications.

Klier, Thomas, and Joshua Linn (2015). "Using Taxes to Reduce Carbon Dioxide Emissions Rates of New Passenger Vehicles: Evidence from France, Germany, and Sweden." American Economic Journal: Economic Policy 7 (1): 212-242.

Li, Shanjun, Christopher Timmins, and Roger H. von Haefen (2009). "How Do Gasoline Prices Affect Fleet Fuel Economy?." American Economic Journal: Economic Policy 1(2): 113-37.

Li, Shanjun, Joshua Linn, and Elisheba Spiller (2013). "Evaluating “Cash-for-Clunkers”: Program effects on auto sales and the environment." Journal of Environmental Economics and Management 65 (2): 175-193.

Pachauri, R. K., and A. Reisinger (2007) (eds.). "IPCC fourth assessment report." IPCC, Geneva.

Puhani, P.A. (2012). “The treatment effect, the cross difference, and the interaction term in nonlinear “difference-in-differences” models.” Economic Letters 115: 85-87.

Rivers, Nicholas, and Brandon Schaufele (2014). "New Vehicle Feebates: Theory and Evidence." Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2491552.

Rogan, Fionn, Emer Dennehy, Hannah Daly, Martin Howley, and Brian P. Ó. Gallachóir (2011). "Impacts of an emission based private car taxation policy–first year ex-post analysis." Transportation Research Part A: Policy and Practice 45(7): 583-597.

Sallee, James M. (2014). “Rational Inattention and Energy Efficiency.” Journal of Law and Economics 57: 781-820.

Sandler, Ryan (2012). “Clunkers or Junkers? Adverse Selection in a Vehicle Retirement Program.” American Economic Journal: Economic Policy 4(4): 253-281.

Stitzing, Robin (2015). “Welfare Effects and Environmental Impact of an Emissions-Differentiated Car Sales Tax.” EAERE Conference, 2015, Helsinki.

Sullivan, J.L., Baker, R.E., Boyer, B.A., Hammerle, R.H., Kenney, T.E., Muniz, L. and Wallington, T.J., (2004). “CO_2 emission benefit of diesel (versus gasoline) powered vehicles.” Environmental science & technology 38(12): 3217-3223.

Swiss Agency for the Environment, Forest and Landscape (SAEFL, 2004). “Pollutant emissions from road transport 1980-2030” Available at http://www.bafu.admin.ch/climatereporting/00545/index.html?lang=en.

Swiss Federal Office for the Environment (SFOE, 2014). “Entwicklung der Treibhausgasemissionen seit 1990.“ Excel-File, available at http://www.bafu.admin.ch/klima/09570/09574/index.html?lang=de&download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1acy4Zn4Z2qZpnO2Yuq2Z6gpJCHdn95g2ym162epYbg2c_JjKbNoKSn6A--

Swiss Federal Statistics Office (SFSO, 2015). “Bundesamt für Statistik, Neue Inverkehrsetzungen von Strassenfahrzeugen in der Schweiz.” Available at http://www.bfs.admin.ch/bfs/portal/en/index/themen/11/03/blank/02/01/02.html

Yamamoto, Toshiyuki, Jean-Loup Madre, and Ryuichi Kitamura (2004). "An analysis of the effects of French vehicle inspection program and grant for scrappage on household vehicle transaction." Transportation Research Part B: Methodological 38 (10): 905-926.

Zachariadis, T., & Clerides, S. (2015). Feebates as a Fiscal Measure for Green Transportation: Insights from Europe and Policy Implications. Available at http://www.greengrowthknowledge.org/sites/default/files/Zachariadis_Feebates_as_a_Fiscal_Measure_for_Green_Transportation.pdf

Table 1. Bonus/malus schemes evaluated in this paper

			Malus			Bonus		
Canton	**Policy**	**Year**	**Criteria**	**Retroactive**	**Amount**	**Criteria**	**Retroactive**	**Amount**
Obwalden	Bonus/Malus	2009	Label G	Yes	+ CHF 60	Labels A and B	No	- 100 %
Geneva	Bonus/Malus	2010	> 200 g CO_2/km	No	+ 50 % of tax	< 121 g CO_2/km	No	- 50%

Source: Kantonale Motorfahrzeugsteuern: Rabatte für energieeffiziente Fahrzeuge. Available at http://www.bfe.admin.ch/energieetikette/00886/02038/index.html?dossier_id=02083&lang=de

Table 2. Study design

Policy	**Policy/treatment**	**Treated group**	**Control group**	**Have data before and after the treatment for both groups?**
Bonus for low emitters and Malus for high emitters in Obwalden (existing and new vehicles)	Bonus/Malus	Existing high emitters in Obwalden at the moment that policy is implemented (2009)	Existing high emitters in canton Uri in 2009	Yes
Bonus for low emitters and Malus for high emitters in Geneva canton (only new vehicles)	Bonus/Malus	Existing high emitters in Geneva at the moment that policy is implemented (2010)	Existing high emitters in 9 cantons with no policy in 2010	Yes

Table 3. Percentage of used inefficient vehicles (fuel efficiency label G) registered in Obwalden and registered the following year in Obwalden or one of the nine cantons with no policy in place.

Canton	**Obwalden**	**Aargau**	**Jura**	**Luzern**	**Neuchatel**	**Schaffhausen**	**Solothurn**	**Schwyz**	**Uri**	**Zug**
2006	84.73	0.00	0.07	0.14	1.51	0.00	0.00	0.28	0.14	0.14
2007	85.42	0.00	0.06	0.39	1.67	0.00	0.19	0.13	0.06	0.19
2008	84.91	0.00	0.06	0.19	1.48	0.00	0.37	0.31	0.06	0.25
2009	83.61	0.00	0.06	0.18	1.62	0.18	0.24	0.36	0.30	0.30
2010	83.75	0.00	0.06	0.23	1.17	0.23	0.58	0.23	0.23	0.41
2011	81.74	0.00	0.06	0.29	1.92	0.35	0.12	0.52	0.29	0.17
2012	78.90	0.00	0.18	0.06	1.87	0.06	0.06	0.18	0.12	0.24
2013	75.46	0.00	0.07	0.13	1.38	0.26	0.26	0.59	0.20	0.33

Source: Own estimations. Assembling of our data is described in section 4.1

Table 4. Percentage of used inefficient vehicles (emitting more than 200 g CO_2/km) registered in Geneva in a given year and registered in the following year in Geneva or in one of the nine cantons with no policy in place.

Canton	**Geneva**	**Aargau**	**Jura**	**Luzern**	**Neuchatel**	**Schaffhausen**	**Solothurn**	**Schwyz**	**Uri**	**Zug**
2006	95.13	0.15	0.05	0.07	0.17	0.01	0.06	0.05	0.01	0.05
2007	94.85	0.15	0.04	0.09	0.14	0.01	0.06	0.08	0.01	0.08
2008	95.41	0.18	0.04	0.09	0.16	0.01	0.08	0.05	0.01	0.04
2009	94.69	0.16	0.08	0.19	0.19	0.06	0.06	0.05	0.01	0.04
2010	95.05	0.17	0.04	0.09	0.17	0.01	0.08	0.07	0.01	0.08
2011	94.73	0.16	0.06	0.11	0.19	0.03	0.06	0.06	0.01	0.06
2012	94.66	0.16	0.05	0.06	0.17	0.02	0.06	0.05	0.00	0.05
2013	94.32	0.13	0.06	0.13	0.22	0.01	0.08	0.07	0.01	0.06

Source: Own estimations. Assembling of our data is described in section 4.1

Table 5. Matching of treated and control cantons: results from the Coarsened Exact Matching algorithm

	Matching variables used in the Coarsened Exact Matching algorithm[a]								
Canton	vintage	CO_2	Label	fuel	weight	vintage CO_2	vintage CO_2 label	vintage CO_2 fuel	vintage CO_2 weight
Treated cantons									
Obwalden	X	X	---	X	X	X	---	---	X
Geneva			---	X			---	---	
Potential control cantons									
Aargau		X							
Jura									
Luzern				X					
Neuchatel					X				
Schaffhausen		X							
Solothurn	X			X		X			
Schwyz		X							
Uri	X	X			X	X			X
Zug				X					
All 9 cantons									

[a]An "X" denotes that the canton is part of the matched set.

Table 6. Determinants of vehicle retirement: Results from Weibull proportional hazard models. Treated canton: Obwalden. Control canton: Uri. Vehicles: vehicles with fuel efficiency label G registered in 2005-2013.

Treated canton: Obwalden	Control canton: Uri									
	Time-invariant controls (I)		(I) + Obwalden dummy (II)		(I) + Post 2009 dummy (III)		(II) + Post 2009 dummy (IV)		(IV) + Interaction dummy (V)	
	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio
Policy evaluation variables										
Post 2009 (A)					-1.075***	0.341	-1.299*	0.273	-1.450**	0.235
(1/0)					(0.133)		(0.668)		(0.684)	
Obwalden (B)			-1.110				-1.088***	0.337	-1.269***	0.281
(1/0)			(0.684)				(0.133)		(0.147)	
Treatment effect (A*B)									0.513***	
(1/0)									(0.152)	
Controls										
Age in 2005	0.101*	1.106	0.0980*	1.103	0.106**	1.112	0.103*	1.108	0.104*	1.110
	(0.053)		(0.053)		(0.0532)		(0.052)		(0.053)	
Log of distance to closest city	0.892**	2.440	0.835**	2.305	0.811*	2.250	0.739*	2.094	0.681*	1.976
(Log of meters)	(0.410)		(0.405)		(0.421)		(0.416)		(0.413)	
Log of median of altitude	-0.125		-0.111		-0.106		-0.089		-0.077	
(Log of meters)	(0.096)		(0.099)		(0.103)		(0.106)		(0.108)	
Baseline hazard parameters										
Intercept	-1.957**	0.141	-1.116		-2.399**	0.091	-1.271		-1.185	
	(0.954)		(1.079)		(0.991)		(1.064)		(1.081)	
Log shape parameter (C)	0.581***		0.579***		0.887***		0.890***		0.892***	
	(0.032)		(0.032)		(0.046)		(0.045)		(0.045)	
Shape parameter	1.788		1.784		2.428		2.435		2.440	
(exp(C))										
Fixed effects										
Trim	YES		YES		YES		YES		YES	
Number of observations	10747		10747		10747		10747		10747	
Number of vehicles	1811		1811		1811		1811		1811	
Number of retirements	930		930		930		930		930	
Log-likelihood	-1071.7		-1069.8		-1035.4		-1032.8		-1027.5	
Akaike information criterion	2611.4		2609.6		2534.7		2533.6		2525.0	

Estimates significant at *10%, **5%, and ***1% level

Table 7. Determinants of vehicle retirement: Results from Weibull proportional hazard models. Treated canton: Geneva. Control cantons: Nine cantons with no policy. Vehicles: vehicles emitting 200 or more g CO_2/km registered in 2005-2013

	Control canton: All									
Treated canton: Geneva	**Time-invariant controls (I)**		**(I) + Geneva dummy (II)**		**(I) + Post 2010 dummy (III)**		**(II) + Post 2010 dummy (IV)**		**(IV) + Interaction dummy (V)**	
	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio
Policy evaluation variables										
Post 2010 (A)					-0.405***	0.667	-0.405***	0.667	-0.391***	0.676
(1/0)					(0.012)		(0.012)		(0.0140)	
Geneva (B)			-0.738***	0.478			-0.760***	0.468	-0.713***	0.490
(1/0)			(0.164)				(0.162)		(0.161)	
Treatment effect (A*B)									-0.141***	0.868
(1/0)									(0.023)	
Controls										
Age in 2005	0.129***	1.138	0.129***	1.138	0.127***	1.135	0.127***	1.135	0.127***	1.135
	(0.004)		(0.004)		(0.004)		(0.004)		(0.004)	
Log of distance to closest city	0.0281		0.0283		0.028		0.0288		0.0280	
(Log of meters)	(0.039)		(0.03)		(0.040)		(0.041)		(0.041)	
Log of median of altitude	0.0193		0.0190		0.0207		0.0203		0.0202	
(Log of meters)	(0.033)		(0.033)		(0.033)		(0.033)		(0.033)	
Baseline hazard parameters										
Intercept	-2.844***		-2.803***		-2.958***		-2.914***		-2.918***	
	(0.339)		(0.334)		(0.348)		(0.343)		(0.343)	
Log shape parameter (C)	0.350***		0.350***		0.470***		0.470***		0.470***	
	(0.004)		(0.004)		(0.007)		(0.007)		(0.007)	
Shape parameter (exp(C))	1.419		1.419		1.600		1.600		1.600	
Fixed effects										
Trim	YES		YES		YES		YES		YES	
Number of observations	1713804		1713804		1713804		1713804		1713804	
Number of vehicles	312656		312656		312656		312656		312656	
Number of retirements	127498		127498		127498		127498		127498	
Log-likelihood	-256440.9		-256423.0		-255170.1		-255150.9		-255123.8	
Akaike information criterion	517229.7		517194.0		514688.2		514649.9		514599.6	

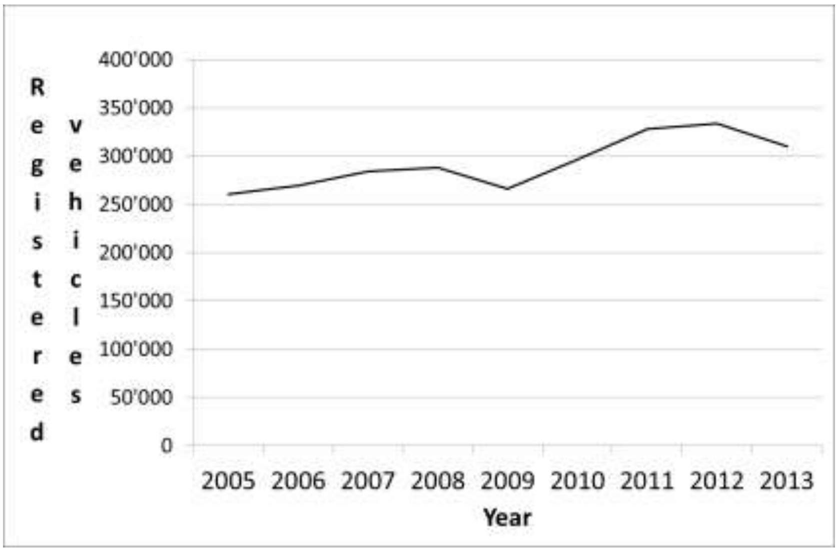
Estimates significant at *10%, **5%, and ***1% level

Table 8. Impact of bonus/malus policy on expected age at retirement. (illustrative vehicle is assumed of age six in 2005)

	Age to retirement (years)			95% C.I. of difference[a]	
Vehicle	**Counterfactual**	**Treated**	**Difference**	**Lower Bound**	**Upper Bound**
			Obwalden		
Toyota Corolla	10.67	9.80	0.86	0.33	1.89
Toyota RAV	10.36	9.53	0.80	0.30	1.81
Hyundai Santamo	9.11	8.52	0.57	0.23	1.25
			Geneva		
Toyota Corolla	10.35	11.03	-0.67	-1.61	-0.14
Toyota RAV	10.36	11.06	-0.67	-1.50	-0.15
Hyundai Santamo	8.80	9.24	-0.42	-1.14	-0.09

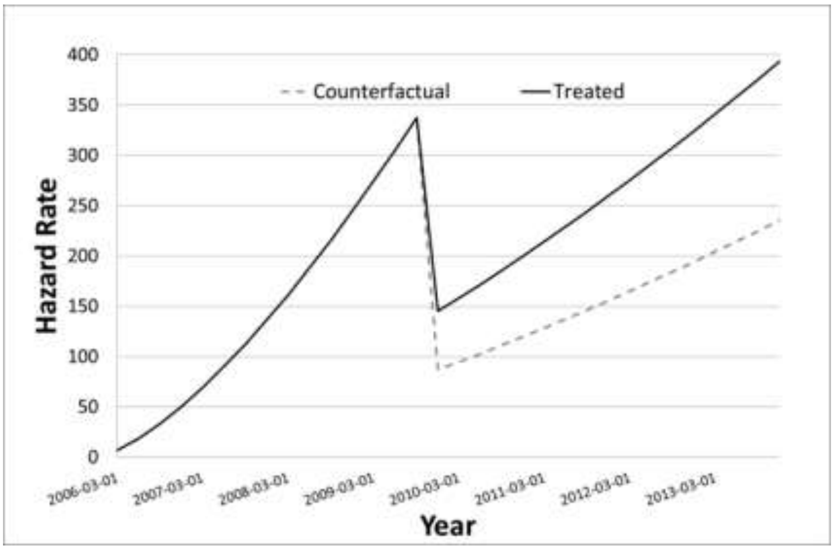
[a] Confidence interval is obtained through 10,000 Krinsky-Robb draws.

Figure 1. Registration of new passenger vehicles in Switzerland, 2005 - 2012



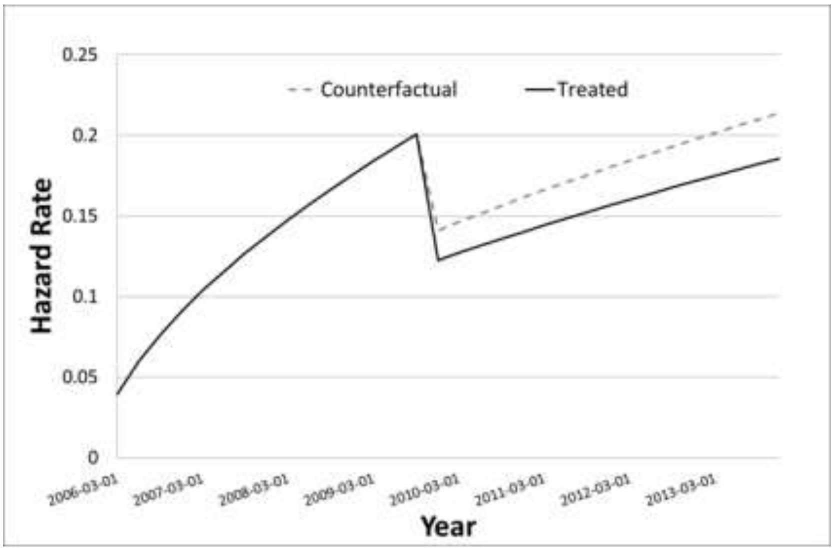
Source: Swiss Federal Statistics Office (2015).

Figure 2. Comparison of estimated hazard rate of retirement in Obwalden Illustrative vehicle is assumed to be aged 6 in 2005.



Source: Own estimates, based on specification (V) reported in table 6.

Figure 3. Comparison of estimated hazard rate of retirement in Geneva Illustrative vehicle is assumed to be aged 6 in 2005).



Source: Own estimates, based on specification (V) reported in table 7.

APPENDIX A. Vehicle fleet composition in treated and potential control cantons in 2005

Table A.1 Percentage (%) of vehicles by vintage period in each canton in 2005

Canton	Vintage period			
	<1990	1991-1995	1996-2000	2001-2005
Treated cantons				
Geneva	18.71	17.09	28.31	35.91
Obwalden	13.52	22.41	32.88	31.19
Potential control cantons				
Aargau	12.81	18.79	31.75	36.66
Jura	15.41	19.91	30.26	34.41
Luzern	10.38	19.35	33.91	36.36
Neuchatel	13.84	17.5	30.23	38.42
Schaffhausen	17.47	20.18	30.53	31.82
Solothurn	13.25	20.61	31.51	34.64
Schwyz	14.66	19.01	31.01	35.33
Uri	14.36	21.85	33.64	30.15
Zug	13.22	13.35	29.76	43.66
All 9 cantons	13.04	18.85	31.69	36.42

Source: Own calculations. See section 4.1 for details.

Table A.2 Percentage (%) of vehicles by range of CO_2 emissions in each canton in 2005

Canton	Range of CO_2 emissions (g/km)		
	<150	150-199	>=200
Treated cantons			
Geneva	6.35	24.68	68.97
Obwalden	5.43	23.22	71.35
Potential control cantons			
Aargau	5.67	24.59	69.74
Jura	6.44	29.66	63.91
Luzern	6.19	27.24	66.57
Neuchatel	7.76	30.57	61.67
Schaffhausen	5.04	21.73	73.23
Solothurn	6.00	25.75	68.25
Schwyz	4.61	22.22	73.17
Uri	4.74	24.05	71.21
Zug	5.22	23.16	71.62
All 9 cantons	5.88	25.57	68.55

Source: Own calculations. See section 4.1 for details.

Table A.3 Percentage (%) of vehicles by fuel efficiency label in each canton in 2005

Canton	Fuel efficiency label (2004 revision)						
	A	B	C	D	E	F	G
Treated cantons							
Geneva	9.81	5.76	16.66	19.95	22.63	15.44	9.76
Obwalden	7.04	6.87	16.33	20.5	20.07	15.57	13.61
Potential control cantons							
Aargau	7.63	5.72	14.43	19.47	21.31	16.91	14.53
Jura	8.78	6.63	19.51	22.33	20.12	13.52	9.11
Luzern	8.21	5.89	15.69	21.44	21.66	15.5	11.61
Neuchatel	10.04	7.42	17.96	20.66	20.77	13.86	9.29
Schaffhausen	7.69	5.88	14.35	19.49	21.38	17.13	14.08
Solothurn	7.25	6.02	16.31	20.93	21.51	16.23	11.77
Schwyz	7.95	5.18	13.48	18.21	21.89	17.71	15.59
Uri	10.74	5.24	14.17	20.03	24.07	16.33	9.42
Zug	7.53	5.37	13.42	18.3	21.03	17.26	17.11
All 9 cantons	8.03	5.92	15.31	20.08	21.38	16.22	13.07

Source: Own calculations. See section 4.1 for details.

Table A.4 Percentage (%) of vehicles by fuel and weight range in each canton in 2005

Canton	Fuel		Range of total weight (tons)			
	Gasoline	Diesel	<1.49	1.50-1.72	1.73-1.95	>=1.96
Treated cantons						
Geneva	91.22	8.78	29.37	23.13	22.79	24.71
Obwalden	89.91	10.09	23.43	24.73	27.52	24.32
Potential control cantons						
Aargau	90.86	9.14	22.39	24.74	26.04	26.83
Jura	89.95	10.05	28.82	27.20	24.01	19.97
Luzern	90.65	9.35	23.33	25.66	26.69	24.32
Neuchatel	88.18	11.82	27.81	26.42	24.18	21.59
Schaffhausen	90.56	9.44	24.56	24.42	25.51	25.51
Solothurn	91.82	8.18	25.60	25.24	25.04	24.13
Schwyz	90.69	9.31	21.26	24.01	26.69	28.03
Uri	90.32	9.68	22.56	27.36	28.11	21.97
Zug	89.44	10.56	17.71	21.17	25.64	35.48
All 9 cantons	90.54	9.46	23.48	24.97	25.80	25.75

Source: Own calculations. See section 4.1 for details.

APPENDIX B. Robustness checks for the Geneva case

Table B.1 Determinants of vehicle retirement: Results from Weibull proportional hazard models. Treated canton: Geneva. Control canton: Solothurn. Vehicles: vehicles emitting 200 or more g CO_2/km registered in 2005

Treated canton: Geneva	Control canton: Solothurn									
	Time-invariant controls (I)		(I) + Geneva dummy (II)		(I) + Post 2010 dummy (III)		(II) + Post 2010 dummy (IV)		(IV) + Interaction dummy (V)	
	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std errors	Hazard ratio	Coeff (std error)	Hazard ratio
Policy evaluation variables										
Post 2010 (A)					-0.374***	0.688	-0.375***	0.687	-0.350***	0.705
(1/0)					(0.036)		(0.036)		(0.045)	
Geneva (B)			-1.862***	0.155			-1.861***	0.156	-1.845***	0.158
(1/0)			(0.189)				(0.186)		(0.187)	
Treatment effect (A*B)									-0.0606*	0.941
(1/0)									(0.035)	
Controls										
Age in 2005	0.136***	1.146	0.136***	1.146	0.134***	1.143	0.134***	1.143	0.134***	1.143
	(0.008)		(0.008)		(0.008)		(0.008)		(0.008)	
Log of distance to closest city	0.057		0.059		0.057		0.059		0.058	
(Log of meters)	(0.061)		(0.061)		(0.061)		(0.061)		(0.061)	
Log of median of altitude	0.011		-0.001		0.0118		-0.001		-0.001	
(Log of meters)	(0.048)		(0.049)		(0.049)		(0.049)		(0.049)	
Baseline hazard parameters										
Intercept	-3.282***		-2.797***		-3.349***		-2.852***		-2.863***	
	(0.540)		(0.546)		(0.535)		(0.544)		(0.544)	
Log shape parameter (C)	0.302***		0.300***		0.417***		0.417***		0.417***	
	(0.012)		(0.012)		(0.020)		(0.020)		(0.020)	
Shape parameter	1.350		1.350		1.517		1.517		1.517	
(exp(C))										
Fixed effects										
Trim	YES		YES		YES		YES		YES	
Number of observations	407819		407819		407819		407819		407819	
Number of vehicles	76525		76525		76525		76525		76525	
Number of retirements	26936		26936		26936		26936		26936	
Log-likelihood	-49552.3		-49458.0		-49329.4		-49234.0		-49231.2	
Akaike information criterion	102174.7		101982.1		101728.8		101536.0		101532.4	

Estimates significant at *10%, **5%, and ***1% level

Table B.2 Determinants of vehicle retirement: Results from Weibull proportional hazard models. Treated canton: Geneva. Control canton: Uri. Vehicles: vehicles emitting 200 or more g CO_2/km registered in 2005

Treated canton: Geneva	Control canton: Uri									
	Time-invariant controls (I)		(I) + Geneva dummy (II)		(I) + Post 2010 dummy (III)		(II) + Post 2010 dummy (IV)		(IV) + Interaction dummy (V)	
	Coeff (std errors	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio	Coeff (std error)	Hazard ratio
Policy evaluation variables										
Post 2010 (A)					-0.293***	0.746	-0.292***	0.747	-0.223***	0.800
(1/0)					(0.038)		(0.038)		(0.083)	
Geneva (B)			-1.846***	0.158			-1.830***	0.160	-1.793***	0.166
(1/0)			(0.227)				(0.227)		(0.229)	
Treatment effect (A*B)									-0.108	
(1/0)									(0.093)	
Controls										
Age in 2005	0.157***	1.170	0.156***	1.169	0.155***	1.168	0.154***	1.166	0.154***	1.166
	(0.012)		(0.012)		(0.012)		(0.012)		(0.0128)	
Log of distance to closest city	0.104		0.105		0.103		0.104		0.103	
(Log of meters)	(0.071)		(0.071)		(0.071)		(0.071)		(0.071)	
Log of median of altitude	0.105***	1.111	0.0989***	1.104	0.108***	1.114	0.102***	1.107	0.101***	1.106
(Log of meters)	(0.037)		(0.036)		(0.037)		(0.036)		(0.036)	
Baseline hazard parameters										
Intercept	-4.556***		-3.520***		-4.637***		-3.559***		-3.599***	
	(0.612)		(0.525)		(0.614)		(0.524)		(0.524)	
Log shape parameter (C)	0.283***		0.280***		0.376***		0.373***		0.374***	
	(0.019)		(0.019)		(0.022)		(0.022)		(0.022)	
Shape parameter	1.327		1.323		1.456		1.452		1.454	
(exp(C))										
Fixed effects										
Trim	YES		YES		YES		YES		YES	
Number of observations	142825		142825		142825		142825		142825	
Number of vehicles	26726		26726		26726		26726		26726	
Number of retirements	9530		9530		9530		9530		9530	
Log-likelihood	-18303.7		-18266.1		-18255.2		-18218.0		-18215.1	
Akaike information criterion	38193.4		38124.3		38104.4		38030.0		38024.2	

Estimates significant at *10%, **5%, and ***1% level

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