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ABSTRACT

The Effects of Cash for Clunkers on Local Air Quality*

We study the effects of a large car scrappage scheme in Germany on new car purchases and local air quality by combining vehicle registration data with data on local air pollutant emissions. For identification we exploit cross-sectional variation across districts in the number of cars eligible for scrappage. The scheme had substantial effects on car purchases and did not simply reallocate demand across time in the short-term. Nevertheless, about half of all subsidized buyers benefited from windfall gains. The renewal of the car stock improved local air quality suggesting substantial mortality benefits that likely exceed the cost of the policy. While policy take-up is somewhat smaller in urban districts, improvements in air quality and health tend to be larger due to a higher car density.

JEL Classification: H20, H23, Q53, Q58

Keywords: cash for clunkers, local air quality, car scrappage schemes, emissions, car rebate

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1 Introduction

Air pollution in cities has become a major concern in recent years, as many densely populated urban areas face serious violations of air quality standards. In 2016, 23 out of 28 EU member states and more than 130 cities broke the EU standards for air pollution, with potentially severe consequences for citizens well-being.[1] This led to increased attention to the causes and consequences of air pollution. Automobile traffic has come under particular public scrutiny as it is a major contributor to air pollution through particulate matter (PM) and nitrogen oxide (NO_x) emissions close to the ground, where it is particularly harmful to human health (see e.g. Knittel et al. (2016), Simeonova et al. (2019), Wolff (2014)). For instance, in Germany traffic contributed 40 percent to all NO_x emissions in 2018 and an even higher share in metropolitan areas. In response, governments are taking various measures to reduce local traffic pollution: some European cities have implemented congestion charges (e.g. London, Milan or Stockholm), others use low emission zones to ban old cars from city centers (e.g. Brussels, Berlin, Paris) and some governments are providing car rebate schemes and subsidies to incentivize purchases of environmentally friendly cars (e.g. the US, Germany or the UK).

In this paper, we focus on the last of these measures by studying the effects of a large car scrappage scheme on new vehicle purchases and *local* air pollution.[2] In particular, we study the impact of Germany's 2009 *Umweltprämie* ("environmental premium"). Implemented in response to the Great Recession as a temporary fiscal stimulus measure, the scheme provided incentives for consumers to buy new cars by providing a lump-sum subsidy of 2500 EUR for each newly purchased car when the buyer at the same time retired an at least 9 years old used car – a *clunker*. The environmental aim of the policy was thus to renew the car fleet in Germany through the replacement of old cars with less pollution-intensive new cars. Similar schemes have been implemented in other countries during the Great Recession (e.g. the US, the UK or France). With a total budget of 5 billion EUR – which allowed for a replacement of 4.8 percent of the stock of passenger vehicles (or 2 million cars) – and a program duration of 9 months from January to September 2009, the German program represented however by far the largest of these schemes.

The key challenge when analyzing the effects of car scrappage schemes on car purchases and local air pollution is that one does not observe car purchases and air pollution levels in the absence

[1] Currie and Neidell (2005), Deryugina et al. (2019) and Deschenes et al. (2017) show that air pollution impairs public health. There is also evidence that pollutants decrease workplace productivity (see e.g. Graff Zivin and Neidell (2012), Chang et al. (2019), Fu et al. (2018)).

[2] We use data on new vehicle registrations to identify new car purchases. In the remainder of the paper we will use the terms "car purchases", "car sales" and "vehicle registrations" interchangeably.

of the policy. To identify the effects of the program, we hence adapt an identification strategy proposed by Mian and Sufi (2012) to the German context: we isolate cross-sectional variation in exposure to the program, by exploiting that the number of *clunkers (*i.e. cars older than 9 years and hence eligible for the program) varies across districts. Exploiting such regional variation still poses some threats to identification. Regions with a larger number of clunkers may differ in local demographic or economic characteristics that may affect car purchases or local air quality. To rule out such concerns, we document pre-treatment correlations of local demographic and economic characteristics with our measure of treatment exposure and show that our results are robust to the inclusion of such control variables. We further show in event-study graphs that there are no pre-trends in car purchases and that our identification strategy can account for potential pre-trends in pollutant concentration. Additionally, we perform placebo tests, analyzing the effects on sulfur dioxide, a local pollutant that is unrelated to traffic.

For the empirical analysis, we combine data from two main sources. We use data on vehicle registrations from the German Federal Motor Transport Authority (*Kraftfahrtbundesamt*) and data on pollutant concentrations (nitrogen dioxide (NO_2), particulate matter (PM_{10}), and sulfur dioxide (SO_2)) from the German Environmental Agency (*Umweltbundesamt*).

We start by showing descriptively that the policy predominantly increased purchases of small and compact cars, in line with the notion that the lump-sum nature of the subsidy gives the strongest incentives to consumers buying small (or low-priced) cars. We also show indicative evidence that the policy induced some consumers to downgrade: while 84 percent of all newly purchased cars with the policy were compact cars or smaller, only 74 percent of the scrapped cars were, with the remainder being larger sized cars.

We next analyze the effects of the policy on car purchases by using an event-study approach. The policy had substantial effects on car purchases. It induced about 1 million additional car purchases in 2009, which is equivalent to an increase in purchases of around 70 percent relative to the pre-policy period. As the policy subsidized a total of 2 million cars, the estimated effects imply that the policy constituted windfall gains for around half of all subsidized buyers. These buyers would also have purchased a car in the absence of the policy. We show that the composition of cars changed towards a less pollution-intensive fleet in response to the policy. We find little sign of purchases predominantly being pulled forward from the immediately following years, as car purchases revert to the original level after the policy ended. We can, however, not entirely rule out the existence of smaller pull-forward effects each year that stretch over a longer period.[3] The findings thus indicate that the program was at least temporarily successful

[3] There may also have been car purchases pulled forward in the year of the policy (i.e. within the policy period

in rejuvenating the car fleet in Germany, which is an important pre-condition for the estimation of the effects on local air pollution.

We then turn to analyzing the effects on local air quality. The car scrappage scheme led to an average reduction of NO_2 emissions by about 1.17 $\mu g/m^3$, which is equivalent to an improvement in local air quality with respect to NO_2 emissions by about 7 percent relative to 2008. There is some indication that the policy also reduced PM_{10} emissions, however the evidence is more mixed. The results are robust to the inclusion of control variables accounting for potential differences in pre-treatment local economic conditions and can neither be explained by differential trends during the Great Recession. Moreover, we find no evidence for a statistically significant effect on SO_2 emissions, which are local pollutants unrelated to traffic. Taken together, these findings suggest that our results are indeed driven by the policy and not by other unobserved factors.

There are important spatial heterogeneities in the effects. While in districts with a larger population and in more urban districts policy take-up is somewhat smaller, improvements in local air quality are larger. We show that the higher density of cars in these areas matters for local air quality improvements. To evaluate the policy's effect on local air quality, it thus does not only matter where incentives are strongest to replace cars, but also whether there are heterogeneities in the impact of each replaced car on emissions.

Finally, we conduct back-of-the-envelope calculations to assess the mortality benefits of the policy. To this end, we combine our estimates of air quality improvements caused by the reduction in NO_2 emissions with existing estimates from the literature on the health impacts of exposure to air pollution and use common income-adjusted life values to monetize avoided deaths. This analysis suggests that the mortality benefits of the policy exceed the budgetary costs and the majority of these benefits accrue to urban areas.

Overall, our results suggest that car scrappage schemes can be at least temporarily successful in rejuvenating the car fleet without just reallocating demand in the short-term, and as a consequence have substantial effects on local air quality. This partially stands in contrast to previous work analyzing scrappage programs. Mian and Sufi (2012) and Hoekstra et al. (2017) find a strong reversal in vehicle purchases following the 2009 US Cars Allowance Rebate Program, similarly Adda and Cooper (2000) find reversals in car sales studying policies in the 1990s in France, while Grigolon et al. (2016) suggest heterogeneity in the effects across programs in eight European countries. The literature studying the environmental impact of such schemes

or the three months after), such effects are attributed to windfall gains in our estimation.

is more sparse.[4] Most notably, Li et al. (2013) find only limited environmental effects following the 2009 US program – in line with the observation that purchases have been pulled forward during that period.[5]

While we cannot directly analyze this, a possible explanation for the differences to these previous findings may be differences in program duration and size. With a total budget of 5 billion EUR allowing for a replacement of 4.8 percent or 2 million passenger vehicles in Germany, the program was considerably larger than the US and French programs (the US program allowed for a replacement of 700k vehicles). Moreover, the program was in place for 9 months, making it also more long-lived than other programs of its kind. In comparison, the 2009 US program only had a total budget of 2.11 billion EUR ($3 billion) and lasted for 2 months.[6] The German program also offered a larger subsidy than the French programs in the 1990s. It may thus be necessary to take factors like program duration and size into account when implementing such a policy.

Our paper further contributes to a broader literature examining the emission reduction potential of tax rebates designed to promote the adoption of low-emission cars, such as Huse and Lucinda (2014) for Sweden, Chandra et al. (2010) for Canada and Beresteanu and Li (2011) and Sandler (2012) for the US. This literature has largely focused on estimating the *hypothetical* impact on CO_2 emissions by using predicted fuel usage and CO_2 emission factors, which is based on a number of assumptions.[7] Instead, our paper is the first to estimate the effects on *actual* on-ground air pollution levels in this context by using data on NO_2 and PM_{10} concentrations that exploits high-quality measurements from the dense official air pollution monitoring network in Germany.[8] Further, focusing on NO_2 and PM_{10} emissions allows us to directly address the question whether car scrappage schemes improve *local* air quality, which is an immediate concern for local and national governments because of its direct impact on individual health.

The paper is structured as follows. Section 2 describes the German *environmental premium* car scrappage scheme. Section 3 describes the data. Section 4 introduces the empirical strategy

[4]There is one contemporaneous study analyzing the effects for Germany. Klößner and Pfeifer (2018), however, focus on *national-level* CO_2 *emissions* and use aggregate data for identification applying a cross-country synthetic control approach.

[5]In principle, there may be environmental effects even if all purchases had been pulled forward if consumers purchased less polluting cars than they would have purchased in the absence of the policy.

[6]Most of the reversal following the US program takes place in the first 8 months after the start of the policy (see Mian and Sufi (2012)). In the German context, purchases pulled forward during that period would still be within the policy period and hence be attributed to windfall gains.

[7]An exception is Sandler (2012), who instead exploits pollution data from laboratory tests of vehicle inspections. These measurements can however diverge significantly from actual on the road pollution as has been shown by Reynaert and Sallee (2021) among others.

[8]*Actual* air pollution data has been used in other contexts. Simeonova et al. (2019) for example analyze the effects of congestion pricing on ambient air pollution and health in Sweden and Bauernschuster et al. (2017) analyze the effects of public transit strikes on ambient air pollution and health in Germany.

used to assess the impact of the car scrappage scheme on car purchases and local air quality. Sections 5 and 6 report the main results and robustness checks. Sections 7 and 8 discuss spatial heterogeneities and the cost-benefit implications of the program, respectively. Section 9 concludes.

2 The *Umweltprämie* - environmental premium

The *Umweltprämie* ("environmental premium") is a car scrappage scheme that was implemented in 2009 in Germany. The scheme provided incentives for consumers to buy new cars by providing a lump-sum subsidy of 2500 EUR for each newly purchased car conditional on several requirements.[9] The main condition required the buyer of the new car to at the same time scrap an at least 9 years old car - a *clunker*. Further restrictions included that the buyer had to be a private person implying that businesses were not eligible for the subsidy and that the car had to be a passenger vehicle. In addition, there was also an environmental requirement: newly purchased cars needed to at least fulfill emission standard Euro 4, which sets legal limits for air pollutants from new vehicles since 2006.[10] This was however, not a very strict requirement as basically all new cars on the market fulfilled these restrictions in 2009. Further, clunkers needed to be registered for at least one year with the applicant, which prevented individuals from buying cheap older cars that would have left the market anyways in order to benefit from the subsidy.

While the official aim of the environmental premium was to renew the car fleet in Germany through the replacement of old cars with less pollution-intensive new cars and hence to reduce emissions of air pollutants in Germany, it should be noted that this program was one of several fiscal stimulus measures implemented during the Great Recession that unfolded in Germany in 2009. Consequently, a second aim of the policy was to stabilize the economy and help the crisis-stricken German car manufacturers during the recession.

Applications for the subsidy could be filed starting January 27, 2009, which was less than 2 weeks after the German cabinet passed the second Great Recession fiscal stimulus package on January 14, 2009, which the environmental premium was part of. As expected given this timeline, we show in Appendix Figure A1 that there were no anticipation effects of the policy using data on google searches from Google Trends for both the word *Umweltprämie* and *Abwrackprämie*

[9] Kaul et al. (2016) estimate an incidence of the policy of slightly below 100 percent for subsidized buyers, indicating that buyers indeed captured most of the subsidy.

[10] Both the policy and the Euro emission standard are independent of fuel or CO2 efficiency requirements for new vehicles.

("scrappage premium") under which the scheme was more generally known.

Initially, the total budget for the scheme was set to 1.5 billion EUR (or 600,000 subsidized cars). The program, however, turned out to be very popular such that the German government decided to top up the budget to 5 billion EUR (or 2 million subsidized cars) at the end of March 2009, at which point already more than 500,000 applications had been submitted (see Figure 1). The scheme, therefore, allowed for a total replacement of 4.8 percent of the stock of passenger vehicles in Germany. The last application was accepted on September 2, 2009, when the budget was exhausted. However, registrations of new vehicles, scrappage of old cars and consequently payouts could still take place until June 2010 and about 15 percent of all subsidy payouts were made in 2010 (see Figure 1). The average age of scrapped cars was 14.4 years and 40 percent of scrapped cars were at least 15 years old (see Appendix Figure A3).

3 Data Sources

For the empirical analysis, we combine data from two main sources. We use data on vehicle registrations from the German Federal Motor Transport Authority (*Kraftfahrtbundesamt*, henceforth KBA) and data on pollutant concentrations from the German Environmental Agency (*Umweltbundesamt*, henceforth UBA). We supplement this data with data on local demographic and economic characteristics from the German Federal Statistical Office and the INKAR database as well as weather data from the German Weather Service (*Deutscher Wetterdienst*, henceforth DWD).

3.1 Vehicle Registration Data

The KBA data contains information on the total stock of passenger vehicle registrations, as well as data on new registrations and ownership changes of private passenger vehicles at the district level for the years 2004 to 2012. We use data on new registrations to identify sales of new passenger vehicles and use the terms "car purchases", "car sales" and "new vehicle registrations" interchangeably. We also have data on the stock of private passenger vehicles and on deregistrations available for a slightly shorter time period between 2007 and 2012.[11] We will use deregistrations as a proxy for car scrappage.[12] Panel B of Table 1 reports summary

[11] There has been a change in the definition of deregistrations in 2007, which also affects the stock measure. Consequently, earlier years of deregistration and stock data are not comparable with the data from 2007 onwards.

[12] Deregistrations can in principle be both temporary or permanent. We nevertheless think of it as a good proxy for scrappage, as usually a car is not deregistered when changing the owner.

statistics describing the KBA data at the district level. In the average district, there have been 3,085 new vehicle registrations, 14,335 ownership changes and 14,342 deregistrations in 2008.[13]

To define the number of cars eligible for scrappage within the program, we use district level data on the stock of vehicle registrations by emission standard provided by the KBA. This data can be used to infer the (approximate) age of a car. We describe this procedure and how we define the measure of cars eligible for scrappage in more detail in Section 4.1. Lastly, we use data on new private vehicle registrations by car segment at the aggregate level to provide descriptive evidence on the type of cars purchased during the program.

3.2 Local Pollution Data

Data on pollution concentration comes from the UBA. We obtained gridded data on yearly average immission concentrations for the pollutants NO_2, PM_{10} and SO_2 measured in $\mu g/m^3$, with grid cells spanning 57 km^2 areas. This data is based on point source measurements from 335 background stations in Germany and is computed using the Optimal Interpolation (OI) methodology, which uses a chemical transportation model to generate a complete spatial distribution of pollution exposure across Germany.[14] This approach ensures that point source information from the observational network is extrapolated taking various factors, such as topology and distribution patterns, into account. The underlying methodology is described in more detail in Flemming and Stern (2004). One of the main advantages of the resulting gridded data over inverse distance-weighted averages derived from the available pollution measuring stations is that it reduces measurement error otherwise occurring in areas with missing point source information (see Auffhammer et al. (2013)). We aggregate the grid cell data to the district level, which is the unit of observation in our study. We do so by computing weighted district level averages in pollution concentration by weighting each grid cell's pollution concentration according to the relative share of the district area covered.[15] This procedure is visualized in Appendix Figure A5.

Panel B of Table 1 reports summary statistics for these pollutants in the year before treatment. The values represent yearly averages of daily mean concentrations computed at the district level. In 2008, average NO_2 concentration across districts has been 16.70 $\mu g/m^3$, average PM_{10} concentration 17.60 $\mu g/m^3$, and average SO_2 concentration 3.42 $\mu g/m^3$. The summary

[13] There are 402 districts in Germany, with on average 204,278 inhabitants (see Table 1, Panel C).

[14] Appendix Figure A4 shows a map with the regional distribution of point source measuring stations in Germany.

[15] Mathematically, this implies that for each pollutant i, each district r and every year t we compute local emission concentrations as $Em^i_{r,t} = \sum_j w_{rj} Em^i_{j,t}$, where j denotes individual grid cells and $w_{rj} = \frac{area_{j \cap r}}{area_r}$.

statistics also show considerable variation in pollutant concentrations across districts.

3.3 Other Data

We amend these two main data sources with district-level data on local demographic and economic characteristics stemming from the German Federal Statistical Office and the INKAR database, a database compiled by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR). This data is used to control for differences in market size across districts and to analyze the robustness of the effects of the environmental premium on car sales and local air quality. The economic and demographic variables used in the empirical analysis are described in more detail in Appendix Table A1. Summary statistics are reported in Table 1, Panel C.

Because pollutant concentration levels are sensitive to weather conditions, we further supplement our data with information from the DWD on yearly precipitation (in mm annual rainfall per m^2) and the average daily mean temperature (in °C). The original data from the DWD is provided in the form of $1km^2$ grids. We aggregate the data to the district level using a similar procedure as the one outlined above for the pollution data. The weather data allows us to reduce noise in the pollution concentration data in the empirical analysis.

4 Empirical Strategy

The key challenge when analyzing the effects of the German *environmental premium* on new car purchases and local air pollution is that we do not observe car purchases and air pollution levels in the absence of the policy. To identify the effects of the program, we hence adapt an identification strategy proposed by Mian and Sufi (2012) to the German context: we isolate cross-sectional variation in exposure to the program, by exploiting that the number of *clunkers (*that is the number of cars eligible for the program) varies across districts.

In this section we outline our empirical strategy. We start by defining the measure of clunkers in a district (Section 4.1). We then describe how we use this measure to identify the effect of the car scrappage scheme on car purchases and local air quality (Sections 4.2 and 4.3). Lastly, in Section 4.4 we analyze correlations in the clunkers measure with local pre-treatment characteristics to test whether districts with a high level of clunkers differ in other regards that might affect car purchases or air pollution levels independent of the policy.

4.1 Definition of Clunkers: Cars eligible for scrappage

We start by defining a measure for the number of *clunkers (*i.e the number of cars eligible for scrappage) at the district level. Because only cars that are at least 9 years old at the time of the policy in 2009 are eligible for scrappage, we would ideally like to use information on the total stock of vehicles by age. This data is, however, not available at the district level. As described in Section 3, we instead have data on the stock of vehicle registrations by EU emission standard for passenger cars at the district level available (referred to as Euro 1 to 6). This information can be used as a proxy, because one can infer the (approximate) age of a car from its emission standard. One possibility would be to define the number of clunkers as all cars older than 9 years at the beginning of 2009. Such a measure would, however, reflect the combination of two sources of variation: (a) (intrinsic) differences in clunkers across regions and (b) differences in fleet turnover timing before 2009 which may be correlated with sales in 2009. As we only want to exploit the former as identifying variation, we instead define the number of clunkers as cars with emission standard Euro 2 or older registered in the district in 2005 ($\#Clunkers_r$), and thus as cars aged 5+ years in 2005. This measure abstracts from any short-term changes in the fleet of cars eligible in the immediate periods before the policy.[16] Using this definition, we only include cars in the clunker measure that are *certainly* older than 9 years in 2009. Cars were required to meet the emission standard Euro 3 from January 2001 onwards. Some car manufacturers however already adhered to this emission standard before 2001. This implies that some eligible cars (aged 9 or 10 years) were emission standard Euro 3. However, less than 10 percent of all cars scrapped within the program fell into that group (see Figure A3). Further, including Euro 3 cars would add a substantial amount of non-eligible cars to the clunker measure, as emission standard Euro 4 was only required from 2006 onwards.

Lastly, because larger districts will mechanically have a larger number of clunkers, we need to normalize the clunker measure by market size to get a measure that is comparable across districts. We follow Mian and Sufi (2012) and normalize clunkers by the number of private purchases of new cars in 2005 such that

$$Clunk_r = \frac{\#Clunkers_r}{\#PrivatePurchases_{r,2005}}. \tag{1}$$

Alternatively, one can normalize the measure by population ($Clunk_r^{pop}$).We provide a robustness

[16] We reestimated all of our results instead measuring the number of clunkers as all cars older than 9 years in a region at the beginning of 2009. As the two measures are highly correlated (0.988), all estimates are very similar when doing so (results available upon request).

check in Section 5.4, where we use this alternative measure. On average, there are 43,674 clunkers in a district, which corresponds to 14.10 clunkers per 2005 purchases and 0.25 clunkers per capita (Table 1, Panel A). Figure 2 further shows that there is considerable variation in the number of clunkers across districts, an important pre-condition when exploiting cross-sectional variation in the number of clunkers to measure exposure to the program. The map also shows that the number of clunkers is particularly high in East German regions. To account for this observed clustering, we will control for federal state (x year) fixed effects in all our specifications and provide a robustness check excluding East German districts in Section 6.3.

4.2 The Effect on Car Purchases

To estimate the effect of the German *environmental premium* on changes in purchases of new cars we then estimate the following regression for the years 2005 to 2012

$$\frac{Purch_{r,t} - Purch_{r,t-1}}{Purch_{r,2005}} = \alpha_{s,t} + \sum_{\tau=2005}^{2012} \beta_\tau Clunk_r \mathbb{1}[t = \tau] + \gamma X_r + \epsilon_{r,t}, \qquad (2)$$

where $Clunk_r$ is our clunkers measure as defined in equation (1), $\alpha_{s,t}$ are federal state x year fixed effects and X_r are potential control variables at the district level to control for local and economic pre-treatment characteristics. The dependent variable represents the change in purchases of new cars between year $t-1$ and t normalized by car purchases in 2005. The coefficients of interest are the β_τ, which are allowed to vary over time and measure the relationship between the initial number of clunkers in a district and changes in new car purchases. If there is an effect of the *environmental premium* on new car purchases, we would expect $\beta_{2009} > 0$ and $\beta_{2010} < 0$ (as purchases should drop in the post-policy year relative to the year of the policy).

Our key identifying assumption is that in the absence of the car scrappage scheme car purchases would have evolved similarly over time in high vs low clunker districts. We can test this assumption by using the pre-treatment coefficients $\beta_{\tau \leq 2008}$. If the assumption is valid, there should be no differential pre-trends between districts with high and low levels of clunkers and hence the $\beta_{\tau \leq 2008}$ should be close to 0 and insignificant. This test further helps to rule out any anticipation effects of the policy.

Additionally, the setting allows us to test whether the policy induced consumers to pull purchases forward from the following years. We do so by summing up the estimated coefficients from equation (2) over time. In the absence of pre-treatment controls, this approach is equivalent to instead estimating regressions with the change in purchases in t relative to 2005 as the dependent variable, that is $\frac{Purch_{r,t} - Purch_{r,2005}}{Purch_{r,2005}}$. We would then expect that the $\beta^{sum}_{\tau \geq 2010}$ are not significantly different from 0 if purchases are not being pulled forward and $\beta^{sum}_{\tau\geq 2010} < 0$ if consumers pull purchases forward.

4.3 The Effect on Local Air Quality

To estimate the effect of the German *environmental premium* on local air quality we focus on estimating the relationship between the number of clunkers in a district and pollutant emissions (i.e. the reduced form). We start by estimating a standard first differences equation with two time periods, where we pool observations over the pre- and post-treatment period respectively to reduce noise in the air pollution data. In particular, we pool observations over a 4-year period both before (2005 to 2008) and after (2009 to 2012) the car scrappage scheme was in place such that the dependent variable is given by

$$\Delta Em^i_r \quad = \quad \frac{1}{4}\sum_{t=2009}^{2012} Em^i_{r,t} - \frac{1}{4}\sum_{t=2005}^{2008} Em^i_{r,t}.$$

We then estimate variants of the following first difference equation

$$\Delta Em^i_r = \alpha^e_s + \beta^e Clunk_r + \gamma^e X_r + \delta^e \Delta W_r + \epsilon^e_r, \tag{3}$$

where $Em^i_{r,t}$ is defined as the yearly concentration average of pollutant i (NO_2, PM_{10} or SO_2) as measured in $\mu g/m^3$, the α^e_s are federal state fixed effects, the X_r potential control variables at the district level to control for local and economic pre-treatment characteristics and ΔW_r controls for changes in weather conditions between the pre- and post-policy period. The parameter of interest is β^e, which measures the relationship between the number of clunkers in a district and the change in average local pollutant emissions before and after the implementation of the *environmental premium*, and hence the average effect of the car scrappage scheme on emissions.

One concern with estimating a first difference specification as in equation (3), is that such a specification may not sufficiently account for potential differential pre-trends in pollutant emissions between high and low clunker districts, and hence that the estimated β-coefficient may not reflect changes in pollutant emissions triggered by the replacement of the car fleet because of the environmental premium, but instead differential trends in emissions.

To account for such a concern, we also estimate an event study, where we analyze the effect of the car scrappage scheme on yearly changes in emissions (i.e. $\Delta Em^i_{r,t} = Em^i_{r,t} - Em^i_{r,t-1}$):

$$\Delta Em^i_{r,t} = \alpha^e_{s,t} + \sum_{\tau=2005}^{2012} \beta^e_\tau Clunk_r \mathbb{1}[t=\tau] + \gamma_r + \delta W^e_{r,t} + \epsilon^e_{r,t}. \tag{4}$$

In our main event-study specification, we include region fixed effects (γ_r) to directly account for region-specific pre-trends in emissions. The effects will then be estimated relative to the change in emissions in a base period, which we will set as the year before the car scrappage scheme was in place (i.e. $\tau = 2008$). The coefficients of interest β^e_τ are now allowed to vary over time, allowing us to analyze the existence of any remaining pre-trends in emissions.

4.4 Validity and Baseline Covariates

Exploiting regional variation by using the (normalized) number of clunkers in a district may pose some threats to identification. First, the question arises why there are more clunkers in some districts than in others and how this is related to the turnover rate of the car fleet. We analyze fleet turnover by documenting pre-treatment correlations of changes in the stock of older cars (emission standard $\leq$ Euro 3) and younger cars (emission standard $\geq$ Euro 4) respectively.[17] The correlations are presented in the upper part of Figure 5. There is a positive association of the stock of clunkers with the change in the stock of older cars and a negative association with the change in the stock of younger cars. Nevertheless, there is no association with respect to the change in new car purchases. These correlations indicate that districts with more clunkers have a slower fleet turnover because of (constantly) lower levels of new car purchases.

Secondly, districts with a larger number of clunkers may differ in local demographic or economic characteristics that may affect changes in car purchases or local air quality over time. To account for such concerns, in the remaining part of Figure 5, we document pre-treatment correlations of local demographic and economic characteristics with our measure of treatment exposure (net of federal state fixed effects). Indeed, more rural districts (with a higher share of employment in the primary sector and a lower level of disposable income per capita) are more likely to have a higher number of clunkers. To account for these observed differences relating to the rurality of a region, we include pre-treatment "market size" controls (population, area and cars per capita) as baseline covariates X_r in all our regressions and show that once we control for these measures, controlling for other local economic characteristics and trends does not considerably change the estimated coefficients anymore. Since the first differences design abstracts from time-constant differences between areas, the correlations of the number of clunkers in a region with pre-treatment growth rates in local characteristics are, however, more important. These correlations are generally less pronounced and economically small.[18]

[17] Emission standard euro 4 was mandatory for new cars from 2006 onwards.

[18] Correlations are generally smaller when excluding East German districts. We therefore rerun all our regressions with the sample restricted to West German districts only. We present the main regressions of this analysis in Section 6.3 (the full set of results is available upon request). The results with the restricted sample are very

We take two additional steps to mitigate concerns about confounding factors. First, as described in Sections 4.2 and 4.3, we conduct detailed year-by-year analyzes showing event study graphs for both the effects on car purchases and local air quality to rule out the existence of differential pre-trends. And second, we provide a placebo test analyzing the effects on SO_2 emissions. SO_2 emissions should not be affected by the 2009 car scrappage scheme, as cars (and other transport) only contribute about 2 percent of total SO_2 emissions.

5 Results: The Effects on Car Purchases

5.1 Descriptive Evidence

We start by analyzing the effects of the car scrappage scheme on new car purchases descriptively using aggregate data on new vehicle registrations at the national level. Figure 3 shows monthly registrations of new private passenger vehicles between January 2008 and December 2012. The figure shows a striking spike in registrations in 2009 – the year the car scrappage scheme was in place. In June 2009, close to 290k new cars were registered, which is about 2.4 times the average number of sales in June in other years. In total, there have been about 2.4 million private passenger cars purchased in 2009, compared to an average of 1.2 million cars in the years surrounding the policy. In Appendix Figure A2, we additionally show monthly deregistrations and ownership changes. In contrast to Figure 3, this figure shows the total number of deregistrations and ownership changes of both privately and business owned vehicles as data on privately owned cars is not available at monthly frequency. The figure shows a clear increase in deregistrations in 2009, indicating a strong increase in cars scrapped because of the policy.[19] There is little sign of purchases predominantly being pulled forward from the immediately following years, as there is no visible decline in car registrations and deregistrations after the policy finished. We will discuss this point in more detail in Section 5.3.

The car scrappage scheme particularly incentivized consumers to buy small cars. Figure 4 shows changes in registrations of new private passenger vehicles relative to the corresponding month in 2008 by nine different segment types.[20] The figure shows that relative to the corresponding month in 2008, the increase in new vehicle registrations was largely concentrated in the 3

similar in magnitudes and not statistically different.

[19] Yearly data shows that the increase in private new car purchases and deregistrations between 2008 and 2009 are actually considerably larger in absolute terms than the increase in total new car purchases and deregistrations, indicating that during the Great Recession commercial buyers may have reduced demand. Note that this does not affect our identification strategy, as these effects are not correlated with our measure of clunkers.

[20] The nine segment types are: mini cars, small cars, compact cars, mid-range cars, mid-range executive cars, luxury cars, SUVs, sports cars and vans.

smallest segment types: mini, small and compact cars (see panel (a) to (c)). In contrast, there is little evidence of an increase in vehicle registrations for larger car types, the exception being vans. Further, there is some indicative evidence that consumers downgrade: while 84 percent of all subsidized cars purchased were compact cars or smaller, only 74 percent of the scrapped cars belonged to these types (see Figure A6). Both observations are in line with the notion that the lump-sum nature of the subsidy gives the strongest incentives for consumers to buy small (or low-priced) cars.

Finally, we provide a first non-parametric analysis of the relationship between the number of clunkers in a district ($Clunk_r$) and car purchases by reporting a scatter plot along with the linear fit of the relationship for the years 2008, 2009 and 2010, in Figure 6. We observe a strong positive relationship between the number of clunkers in a district and the change in car purchases in the year of the policy (2009, Panel (a)). In contrast, there is virtually no relationship between changes in car purchases and the number of clunkers in the year before the policy (2008, Panel (b)) or the year after (2010, Panel (c)).

5.2 Event Study

We then study the effects of the car scrappage scheme on purchases of new cars in a more systematic way by estimating variants of equation (2). The baseline regressions presented in this section only control for federal state x year fixed effects to account for state specific trends in car purchases and baseline covariates (pre-treatment market size controls) as described in Section 4.4.[21] We show robustness checks controlling for other local and economic pre-treatment characteristics in the Section 5.4.

Figure 7(a) plots the estimated impact of a one unit increase in clunkers per 2005 car purchases on the year-by-year growth in new car purchases, while Figure 7(b) plots the estimated change in new car purchases in year t relative to 2005 (see Section 4.2 for details). There is little evidence for a systematic relationship between the number of clunkers in a region and changes in car purchases before 2009 ($t < 0$). The coefficient estimates are precisely estimated and clustered around 0.[22] Both figures show however a striking increase in car purchases in 2009 driven by the program. A one unit increase in clunkers per 2005 car purchases increases car sales by 5.1 percent relative to 2008 and by 5.0 percent relative to 2005. In 2005 (2008), 1,535,453 (1,240,318) new cars have been purchased in Germany, while the average number of normalized

[21] The market size controls do not affect the estimated effects on car purchases.

[22] Germany increased the VAT in January 2007 from 16 to 19 percent. The small differences in 2006 and 2007 are likely driven by this VAT increase.

clunkers in a district was 14.1 (see Table 1, Panel A). This implies that the policy induced about 1 million (890,000) additional car purchases in 2009.[23] This is equivalent to an increase in purchases of 70 percent (72 percent) relative to 2005 (2008). These results also imply that the policy constituted windfall gains for around half of all subsidized buyers. These buyers would also have purchased a new car in the absence of the policy.

Lastly, both figures show a bounce back to the previous level of car purchases in 2010. Figure 7(a) depicts an equivalent reduction in the change in car purchases between 2009 and 2010, while Figure 7(b) demonstrates that car purchases return to (approximately) 2005 levels. We discuss the implications of these results in the next section, where we discuss margins of adjustments in more detail.

5.3 Margins of Adjustment

We are ultimately interested in the impact of the scrappage policy on local air quality. This impact does not only depend on the policy inducing new car purchases, but also on the counterfactual in the absence of the policy. It is therefore important to study the potential margins of adjustment. We have already shown descriptive evidence on one such margin in Section 5.1: downgrading to smaller cars. The policy predominantly induced purchases of small and compact cars and a higher share of new cars than of scrapped cars was compact or smaller (see Figures 4 and A6). In Appendix Figure A7, we further show indicative evidence that it is unlikely that changes in distance per year driven is an important adjustment margin, as traffic on highways and federal roads does not change following the policy.[24] In what follows, we discuss three additional margins. We will first analyze ownership changes and deregistrations. Secondly, we will study whether the policy indeed changed the composition of cars to a less-pollution intensive fleet. Lastly, we will discuss potential pull-forward effects.

Ownership Changes and Deregistrations

Would the consumers induced to buy a new car by the policy have continued to drive their old existing car in the absence of the policy (an on average 14.4 year old clunker, see Figure A3) or would they instead have replaced their clunker by buying a used car?

We can analyze this question using data on ownership changes and deregistrations of cars, using

[23] The calculations are $0.05 \times 14.1 \times 1,535,453 = 1,082,494$ and $0.051 \times 14.1 \times 1,240,318 = 891,912$.

[24] The data comes from the *Federal Highway Research Agency* and provides information on the number of passing vehicles on all highways and federal roads recorded by traffic monitors.

the latter as a proxy for scrappage.[25] We estimate variants of equation (2) with the change in car deregistrations and ownership changes as dependent variables. To make the results directly comparable to the results on car purchases, we normalize both dependent variables by 2005 car purchases (i.e. $\frac{Dereg_{r,t} - Dereg_{r,t-1}}{Purch_{r,2005}}$ and $\frac{OwnerCh_{r,t} - OwnerCh_{r,t-1}}{Purch_{r,2005}}$). The coefficients of interest then measure the effect of a one unit increase in normalized clunkers on the year-by-year change in deregistrations (or ownership changes) normalized by 2005 new car purchases.

If the policy indeed incentivized consumers to buy new cars who would have otherwise kept their old clunkers, then we would expect to see a similar spike in the year-by-year change in deregistrations in 2009 as we have seen in new car purchases in Figure 7(a). We would also expect the number of ownership changes to remain unaffected. Figure 8(a) plots the effects on car deregistrations and 8(b) on ownership changes. We find an increase in car deregistrations in 2009 (and a corresponding reversion in 2010) that strikingly resembles the pattern of the effects on new car purchases: New car purchases increase by 5.1 percent relative to 2008, while deregistrations increase by 4.6 percent. This is a strong indicator that the policy indeed incentivized consumers to buy new cars, who would otherwise not have upgraded their car but instead continued to use the clunker. The effects on ownership changes confirm this impression: While there is some evidence that high clunker districts experience increases in ownership changes over time relative to low clunker districts, there is no indication that ownership changes decrease more in high clunker districts in 2009. If the policy had predominantly incentivized consumers to upgrade to a new car, who would have replaced their clunker with a used car even in the absence of the policy, the number of ownership changes should have dropped instead.

Composition by Emission Standards

We have just shown that the increase in cars scrapped tracks car purchases during the policy period and thus consumers did not just upgrade from buying a used car in the absence of the policy. We will now analyze whether indeed as a consequence of the policy the composition of cars with respect to emissions changed - one of the main aims of the policy. This question is thus important in its own right, but will also help to corroborate the findings on ownership changes and car registrations discussed above. In particular, we will analyze changes in the stock of passenger cars with emission standard Euro 3 or lower (old) and Euro 4 or higher (new), where standard Euro 4 is the required emission standard of the policy. We again estimate equation (2), now with the change in the two respective stock variables as dependent variables

[25] For deregistrations and stock by emission standard we can only use data from 2007 onwards, as there has been a change in the definition of deregistrations in 2007 and hence earlier years of stock and deregistration data are not comparable with the data from 2007 onwards.

and again normalize both dependent variables by 2005 car purchases to make results directly comparable with the effects on new car sales.[26] The resulting estimates represent year-by-year effects. Because the stock data also includes information on fuel type, we estimate separate effects for petrol and diesel cars.

Figure 9(a) plots the effects on the car stock with emission standard Euro 3 or lower and on the stock with emission standard Euro 4 or higher. Effects are predominantly driven by changes in the composition of the petrol car stock. We estimate a decrease in the stock of petrol cars with emission standard Euro 3 or lower of 5.2 percent and a corresponding increase in the stock of petrol cars with emission standard of at least Euro 4 of 4.7 percent - again coinciding with the increase in new car purchases estimated. Despite diesel cars contributing about 25 percent to the total vehicle stock, there is no clear pattern in the effects on the stock of diesel cars. It rather seems that the change in 2009 can be attributed to a slight positive trend in the stock of (new) diesel cars in high clunker regions. This is in line with our descriptive findings that the policy largely induced the purchase of smaller cars (see Figure 4). Most small and compact cars are petrol cars. In Figure 9(b), we dig deeper into the change in composition of older cars by separately analyzing the effects on the stock of cars without Euro emission standard, with emission standard Euro 1 or 2 and emission standard Euro 3. The policy predominantly replaced cars with emission standard Euro 1 or 2 (which are between 10 and about 20 years old).

Pull-forward Effects

A related question is whether the purchases induced by the policy have just been pulled forward from later periods. In Section 5.2 we have documented that private car purchases go back to pre-policy levels.[27] We have also shown in this section that deregistrations react similarly strongly in the policy period, while ownership changes do not decrease considerably neither in the year of the policy nor in the following years. Similarly, we find constant effects on the composition of the car fleet towards a less pollution-intensive fleet. These findings and the lack of a (strong) drop in new car purchases and ownership changes in the immediate years after the car scrappage scheme suggest that car purchases have not just been pulled forward from the directly following

[26] We additionally include district fixed effects to control for potentially differential trends between high and low clunker districts.

[27] It may be that some eligible consumers (i.e. consumers with a clunker for scrappage) pulled purchases forward and some non-eligible consumers postponed the purchase of a car (see e.g. Klößner and Pfeifer (2018)). However, if that was the case, pulled-forward and postponed purchases must cancel out given that we do not find any effects on purchases in 2010. Even in this case, our results still imply that about 1 million additional car purchases have been induced by the policy with the estimated effect representing the net effect.

years and hence that the policy was at least temporarily successful in rejuvenating the car fleet in Germany. However, we cannot entirely rule out that there exist small underlying trends in both new purchases and ownership changes that may prevent us from detecting smaller pull-forward effects that stretch over a longer period. To neutralize the effects over a 10 year period, for instance, 0.6 percent of new purchases or ownership changes pulled-forward each year would be needed.

Our results thus stand in contrast to the findings in Mian and Sufi (2012), who find a strong immediate reversal in vehicle purchases at the end of the 2009 US Cars Allowance Rebate program. One explanation for this discrepancy may be differences in the program duration and size - the US program only lasted for 2 months, had a total budget of 2.11 billion EUR (3 billion USD) and allowed for the replacement of in total 700k cars. Most of the reversal in vehicle purchases in the US took place within 10 months, while the German policy actually lasted over 9 months. We find that around 1 million cars purchased with the subsidy would have been purchased in the policy year (i.e. the policy period or the three months after) even in the absence of the policy - thus in our setting immediate pull-forward effects within the same year are counted as windfall gains. A second explanation may be differences in the German setting. For example, there is suggestive evidence that overproportionally secondary vehicles may have been replaced, as the share of female buyers increased from 32 to 38 percent during the policy period. Such cars may have longer life cycles and may thus be pulled forward from later periods.

5.4 Robustness

The above results demonstrate a striking spike in purchases of new cars in 2009, while there is little evidence for a systematic relationship between the number of clunkers in a district and changes in car purchases both before and after 2009. This makes us confident that the spike is indeed driven by the car scrappage scheme. Given that we have shown in Section 4.4 that districts with a high number of clunkers tend to be more rural, one may nevertheless be worried that other local or economic characteristics drive the spike in 2009. To account for these concerns, we present several robustness checks in Table A2. The reported coefficients represent the estimated differential change in new car purchases relative to 2005. Column (1) replicates the baseline estimates presented in Figure 7(b). In column (2), we add variables that control for differences in local economic characteristics in the pre-treatment period 2008, including the share of workers employed in the primary sector, the employment share of the secondary sector, unemployment, disposable income per capita and productivity per capita. In column (3), we further add the 2005 to 2008 pre-treatment growth rates in population, the unemployment rate, disposable income per capita and productivity per capita.[28] For completeness, in column (4) we add current weather controls, in particular the change in yearly precipitation (in mm annual rainfall per m^2) and the change in the average daily mean temperature (in °C). While these weather controls are unlikely to affect car purchases, they may play a role when analyzing the effects of the car scrappage scheme on local air quality in Section 6. Hence we add this specification to facilitate comparison across outcomes. The results are very stable across these four specifications. In particular, the estimated coefficients in column (2) to (4) are very similar to, and not statistically different from the baseline results in column (1). Moreover, none of the specifications suggest a pre-trend.

In an additional robustness check, we use an alternative definition of the clunkers measure. Instead of normalizing clunkers by 2005 car purchases, we construct a measure of clunkers per capita by normalizing the number of clunkers in a district by the 2008 district population (i.e. $Clunk_r^{pop} = \frac{\#Clunkers_r}{Population_{r,2008}}$). There are on average 0.256 clunkers per capita (see Table 1, Panel A). The results of this specification are presented in column (5) of Table A2. While the scale of the coefficients is different, the pattern of results is very similar to the corresponding specification using the baseline clunkers measure. Furthermore, the implied increase in new car purchases that the policy induced is also comparable with the baseline results, with an estimated increase in car purchases due to the policy of 1.29 million compared to 2005 and 940,000 compared to 2008.[29]

Having established that the German *environmental premium* incentivized the purchase of new cars and led to a rejuvenation of the passenger vehicle stock in Germany in the following years, we analyze in the next section whether local air quality improved as a consequence of this rejuvenation,.

6 Results: The Effects on Local Air Quality

6.1 Pooled Estimates

We start the analysis of policy effects on local air quality by showing estimates of pooled first difference specifications. We pool observations over two 4-year periods in the pre- and post-policy period respectively (i.e. from 2005 to 2008 and 2009 to 2012), as described in Section

[28]We describe the full set of local demographic and economic control variables in more detail in Appendix Table A1

[29]The calculations are $3.274 \times 0.256 \times 1,535,453 = 1,286,930$ and $2.956 \times 0.256 \times 1,240,318 = 938,593$.

4.3, and estimate variants of equation (3). We analyze the effects on NO_2 and PM_{10}, the two main air pollutants caused by car exhausts.

We focus first on the effects on NO_2 emissions. The results are reported in Table 2, columns (1) to (4). We start from the most basic specification that only controls for federal state fixed effects and baseline covariates (pre-treatment market size controls) in column (1) and then step by step add additional control variables to gauge their impact in columns (2) to (4). In the baseline specification in column (1), we find that a one unit increase in clunkers per 2005 car purchases in the region significantly reduces NO_2 emissions by 0.050 $\mu g/m^3$, suggesting a negative impact of the car scrappage scheme on NO_2 emissions. In columns (2) to (4), we then add further control variables to account for potential differences in local economic characteristics in the pre-treatment period 2008 (column (2)), differential pre-treatment growth rates in economic and demographic characteristics (column (3)) and differential developments in weather conditions across regions (column (4)). These additional control variables have only little impact on the estimated policy effect on NO_2 emissions. In our preferred specification, including the full set of controls, a one unit increase in clunkers per 2005 car purchases in the region reduces NO_2 emissions by 0.056 $\mu g/m^3$(see column (4)). This estimated reduction suggests an average overall reduction in NO_2 emissions caused by the policy of 0.79 $\mu g/m^3$ (=0.056 × 14.1) or 4.7 percent (=0.79/16.7) compared to 2008 and hence an improvement in local air quality.[30]

We then analyze the effects on PM_{10} emissions. The results are reported in Table 2, columns (5) to (8). The specifications are equivalent to those employed when estimating the impact on NO_2 emissions. We estimate a negative coefficient of -0.018 $\mu g/m^3$ (column (5)) in the most basic specification including only federal state fixed effects and baseline covariates (pre-treatment market size controls). The inclusion of further control variables does not affect the coefficients much; the specification with the full set controls yields a coefficient of -0.015 $\mu g/m^3$ (column (8)). This indicates that the car scrappage scheme may also have reduced PM_{10} emissions. All coefficients are however measured imprecisely, and we cannot reject the hypothesis that there are no effects on PM_{10} emissions. For that reason, we refrain from making stronger claims regarding the average reduction in PM_{10} emissions caused by the policy here.

6.2 Event Study

While the pooled first difference specification is beneficial to account for potential noise in the emissions data, a remaining concern is that such a specification may not sufficiently account for

[30]The average number of clunkers per 2005 car purchases is 14.1 and the average level of pre-treatment NO_2 emissions across regions is 16.7 $\mu g/m^3$ (see Table 1).

potential differential pre-trends in pollutant emissions between high and low clunker districts. If this is the case, the estimated coefficients may not reflect changes in pollutant emissions triggered by the renewal of the car fleet because of the subsidy scheme, but instead simply represent differential trends in emissions. To account for this concern, we present event study estimates in this section. In particular, we estimate variants of equation (4), with the year-by-year change in local emissions as the dependent variable (i.e. the change between $t-1$ and t) that control for potential differential pre-trends through district fixed effects. In this specification, the effects are estimated relative to the change in emissions the year before the car scrappage scheme was in place (2008).

The main results are presented in Figure 10. We again start by discussing the effects on NO_2 emissions (Figure 10a). The coefficients show a reduction in NO_2 emissions in 2009 (the year of the policy) and in 2010 (we will discuss the 2010 effect further below), and no discernible pre-trends in the pre-treatment period. The estimated coefficients in 2006 and 2007 are close to zero and statistically insignificant. In contrast, there is a strong drop in NO_2 emissions of 0.043 $\mu g/m^3$ in the year of the policy in 2009, then dropping by another 0.072 $\mu g/m^3$ to 0.115 $\mu g/m^3$ in 2010. In the following years, NO_2 emissions continue to be more than 0.08 $\mu g/m^3$ below pre-policy levels, indicating that the effects of the policy are lasting.

In Appendix Table A3, we additionally show that the estimated effects are nearly indistinguishable, when controlling for potential pre-trends by including a baseline measure of the number of clunkers in the district ($Clunk_r$) instead of district fixed effects (column (2)). We further show in column (3), that when estimating the equivalent to the first difference specification presented in column (5) of Table 2, which controls for pre-treatment characteristics only to account for potential differential pre-trends (and not for district fixed effects), there exist small differences in NO_2 emission trends between high and low clunker districts before the policy. NO_2 emissions in high clunker districts seem to be increasing over time relative to NO_2 emissions of low clunker districts. This implies that the simple pooled first difference specifications presented in the last section slightly underestimated the impact of the German *environmental premium* on NO_2 emissions. However, generally these pre-trends are small and not statistically significant from zero.

Why are there such strong effects in 2010 - the year after the policy took place? The main reason is that the replacement of the car fleet took place successively in 2009 and may even have been reaching into 2010. An indicator for this is the observed pattern of premium payouts over time (see Figure 1). Payouts have been administered by the *Federal Office for Economic Affairs and Export Control* on average about 1.5 months after the registration of the newly purchased car. By the end of June 2009, only about 25 percent of customers have had their premium paid out, by the end of September 51 percent and by the end of 2009 85 percent. This suggests that close to 50 percent of all cars bought with the environmental premium have been registered only in the last quarter of 2009 (or later). Consequently – in line with our results – a considerable share of the total effect of the car scrappage scheme on emissions should take place in 2010 only.

The joint effect over the post-policy period (i.e. from 2009 to 2012) suggests an overall reduction in NO_2 emissions in the average district caused by the policy of 1.17 $\mu g/m^3$or 7.0 percent.[31] Is this a plausible effect size? These estimates are comparable in magnitude to estimates by Gehrsitz (2017) and Pestel and Wozny (2019), who find NO_2 reductions of 0.5 and 1.5 $\mu g/m^3$, respectively, analyzing the introduction of so called low emission zones in Germany - a policy banning old cars from city centers. To further gauge the plausibility of the effect size, we conduct back-of-the-envelope calculations using the estimated effects on new car purchases (1 million policy-induced replacements) and information on the emission intensity of cars (see Appendix Table A5). In our preferred specification, we use real-world emissions data by Euro standard from the International Council on Clean Transportation (ICCT (2017)). Based on this data, the average clunker emits about 1.78 g NO_x/km, while the average subsidized vehicle emits only about 0.19 g NO_x/km. We further assume (a) a constant vehicle class composition, and (b) a constant annual mileage of 14,100 km per year.[32] Under these assumptions, we calculate a reduction in emissions of 7.0 percent, which matches our direct emission estimates. Relaxing assumption (a) to account for the indicative evidence that the policy may have led to downgrading to smaller cars by assuming that every fifth car bought with the subsidy was smaller than the scrapped car and that smaller cars are less emission-intensive, we estimate a slightly larger contribution of 7.1 percent.[33] Consequently, downgrading matters very little for the effects. Note that we would underestimate the effects if we used type-approval emissions, which are tested in the laboratory, instead of real-world emissions in the calculations. Such type-approval emissions, are known to underestimate the real-world emissions on the road (Reynaert and Sallee 2021). We would then estimate a reduction of only 4.5 percent. Overall, this analysis confirms the plausibility of our directly estimated effects on local air quality.

[31]The calculations are $(-0.043 - 0.072 + 0.007 + 0.025) \times 14.1 = 1.17$ using the coefficients of Table A3, column (1) and 1.17/16.7.

[32]We do not find considerable changes in distance driven (see Section 5.3). The average mileage of private vehicles in 2008 was 14,150 km (BMVI (2021)).

[33]This is based on the descriptive evidence that 10 percent more subsidized cars were compact cars or smaller than scrapped cars (see Appendix Figure A6) and the assumption that all downgrading was incentivized by the policy. Because data on emissions by car segment is not available, we assume that small Euro 4 and 5 cars emit 50 percent less than the average. Both assumptions imply that we estimate an upper bound of downgrading effects.

The analysis of the effects on PM_{10} emissions in Figure 10b, and Table A3, columns (4) to (6), delivers a similar, albeit not quite as clear picture. The coefficients indicate a negative effect of the policy on PM_{10} emissions. The 2009 and 2010 coefficients in the main specification controlling for district fixed effects are of similar size as the point estimates in the NO_2 regressions, with coefficients of -0.052 and -0.055 $\mu g/m^3$ respectively and a cumulative effect of 0.14 $\mu g/m^3$ (see also Figure 10b). Estimates are however generally more noisy (see Table A3). Given the noise, we view these results as at most *indicative* evidence of a reduction in PM_{10} emissions caused by the policy.

6.3 Robustness

The results presented in Section 6 are robust to a number of alternative specifications. For easier exposition, we start by presenting robustness checks where we estimate pooled regressions estimating variants of equation (3), as described in Section 4.3. We then show additional robustness checks allowing for time varying controls and present a placebo test.

Alternative Pooled Specifications

We present four sets of alternative pooled specifications. The results are presented in Table 3. We first describe the results in Panel A which reports the effects on NO_2 emissions. For comparison, column (1) presents the baseline results (equivalent to Table 2, column (4)). In column (2), we restrict our sample to districts with at least one point source measuring station.[34] The estimated effect is slightly larger than in the baseline regression, possibly a consequence of a reduction in measurement error when relying on districts with measuring stations only. In column (3), we exclude districts from the sample that host car manufacturing firms (or their suppliers), to avoid that some of the effects are driven by direct demand effects in these regions. This reduces the effect slightly. In column (4), we instead only include West-German districts in the estimation. This slightly increases the coefficient. Lastly, in column (5) we allow for a non-linear relationship between the number of clunkers in a district and emissions by using the log-change in emissions as dependent variable. The estimated effect of 0.002 indicates a reduction in NO_2 of 0.2 percent for every additional clunker per 2005 car purchases. As the average number of clunkers per 2005 car purchases is 14.1, this suggests an overall reduction in NO_2 emissions of about 2.8 percent, which is somewhat smaller than the 4.7 percent estimated using the absolute change in emissions as dependent variable (see Section 6.1). All in all, the

[34] There are 189 districts without point source measuring station. See also Figure 2 for the distribution of measuring stations.

results in this section show that the results on NO_2 emissions are largely robust to alternative specification choices.

There is more variability in the estimated effects on PM_{10} emissions. This is not surprising, as we already concluded in Section 6 that the estimated effects can at most be seen as indicative evidence of a reduction in PM_{10} emissions caused by the policy. The estimates are slightly smaller, when excluding districts without measuring stations. They are larger and statistically significant when excluding East German districts.

Time Varying Controls - Great Recession and LEZs

The pooled regressions shown above are not well suited to account for time varying shocks that may be correlated both with the number of clunkers in a region and air pollutant emissions. As the implementation of the car scrappage scheme coincided with the Great Recession, one could be concerned that the estimated effects are not caused by the renewal of the car fleet because of the policy but instead by differential shocks to emissions in high and low clunker districts caused by the recession. To rule out this concern, we now present further robustness checks using the event study specification presented in Section 6.2 that allows for the inclusion of time varying controls. The results of these robustness checks are presented in Figure 11a for NO_2 and 11b for PM_{10}. We present cumulative effects in the figure. The corresponding year-by-year estimates are shown in Appendix Table A4. In the first robustness check, we include a Bartik control as a proxy for (national) industry-driven local demand shocks (*triangles*).[35] This variable absorbs year-by-year variation in local industry activity resulting from national industry shocks and should hence account for changes in emissions that stem from national industry shocks caused by the recession. Second, because we have shown that rural areas are more likely to have a higher number of clunkers and the recession may have differentially affected rural and urban areas, we present a robustness check controlling for dummy variables indicating whether a district is urban interacted with year fixed effects (*diamonds*). This specification flexibly allows for differential trends or time varying shocks to emissions in rural and urban areas. For comparison, we also present the baseline results (*circles*; equivalent to Figure 10). The results are very robust to the inclusion of the Bartik control and urban x year fixed effects; neither of the two measures is significantly affecting the coefficients of interest. This makes us confident that our baseline results are not just caused by differential shocks across regions during the recession, but instead

[35]In particular, we define the Bartik control as $Bartik_{rt} = \sum_j \frac{Empl_{jrt_0}}{Empl_{rt_0}} \Delta\%Empl_{jt}$, where $Empl_{jrt}$ is defined as local employment of industry j in region r and period t, $Empl_{rt}$ as local employment in region r and period t, and $Empl_{jt}$ as the national employment level in industry j and period t. Period t_0 is defined as the year 2005. The employment data comes from statistics of the *Federal Employment Agency*.

by the renewal of the car fleet due to the implementation of the car scrappage scheme by the German government.

Starting in 2008, some German cities successively introduced low emissions zones (LEZ) to restrict the access of vehicles with high PM_{10} emissions to inner-cities.[36] As low emission zones affect local air pollution (see for example Wolff (2014), Gehrsitz (2017) or Pestel and Wozny (2019)) we perform an additional robustness check, controlling for the introduction of LEZs (*squares* in Figure 11). In particular, we include a dummy variable that switches to one in the year the low emission zone is introduced and allow for differential effects on emissions depending on time passed since the introduction. Again, the estimated coefficients are basically unchanged after the inclusion of the LEZ controls, indicating that our estimated pollution reductions cannot be explained by the introduction of low emission zones either.

Placebo Test

To further rule out that our results are driven by confounding factors, we provide a placebo test analyzing the effects on sulfur dioxide emissions (SO_2). SO_2 emissions should not be affected by the 2009 car scrappage scheme, as cars (and other transport) only contribute about 2 percent to total SO_2 emissions.[37] For brevity, we again show the results from pooled regressions, estimating variants of equation (3) as described in Section 4.3, but now with the change in SO_2 as the dependent variable. The results are reported in Table 4. We present the same specifications as in our analyzes on NO_2 and PM_{10} emissions in Section 6.1. There is no discernible relationship between the number of clunkers in a region and growth in SO_2 emissions in the most basic specification controlling for federal state fixed effects and (pre-treatment) market size controls only (column (1)). Controlling for other local economic factors, pre-trends in local economic and demographic variables or changes in weather conditions, does not substantially affect the estimates (columns (2) to (4)). The coefficients are all close to, and not significantly different from zero, as would be expected given the policy should not have an effect on SO_2 emissions.

Overall, the results in this section provide strong evidence that the effects on local air quality are indeed driven by the renewal of the car fleet caused by the implementation of the car scrappage scheme in Germany and not by other events. Most notably, there is no evidence that they are caused by the Great Recession.

[36] By the end of 2012, 49 cities in Germany have introduced such zones.

[37] In 2008, the energy sector contributed around 53 percent, industrial processes around 20 percent, the manufacturing sector around 10 percent and private households around 15 percent to overall SO_2 emissions in Germany.

7 Spatial Heterogeneities

We have shown that the German environmental premium incentivized consumers to buy new and less pollution-intensive cars, which in turn reduced pollutant emissions and thus increased local air quality. In this section we analyze whether these effects differ across space. As the number of clunkers is related to market size and as urban regions and regions with higher population tend to have less clunkers, there may be spatial heterogeneities in policy-induced improvements in local air quality, even if the effects of the policy on car sales are homogeneous. However, effects on car sales can also be heterogeneous. We analyze such spatial heterogeneities in policy take-up and its effects on pollutant emissions by studying the effects by population size, by whether a district is rural or urban, and by car density (per sqkm) in Table 5. We analyze heterogeneities along each dimension by splitting the sample at the median of the respective variable, except for the urban/rural split which is pre-defined. We show the year-by-year effects equivalent to our baseline specifications (presented in Table A2, column (1) and Table A3, column (1)).

We start by analyzing the effects by population size. Columns (1.1) and (1.2) show that policy take-up is somewhat stronger in districts with less population, a one unit increase in clunkers per 2005 car purchases increases car sales by 5.3 percent in less-populated districts, while it increases car sales by 4.9 percent in more-populated districts. Nevertheless, with average absolute reductions of -1.05 $\mu g/m^3$ and -1.46 $\mu g/m^3$, respectively, the effects on NO_2 emissions are larger in more-populated districts (columns (2.1) and (2.2)). A similar picture arises when comparing rural vs urban districts in columns (3.1) to (4.2). The effect on car sales is somewhat higher in rural districts, but absolute NO_2 reductions are considerably more pronounced in urban districts (-2.20 $\mu g/m^3$ compared to -1.34 $\mu g/m^3$).

One explanation for the larger effects on air quality in more populated and more urban districts may be that for local air quality improvements it does not only matter how many cars are replaced, but also in which spatial area. We test this next by analyzing heterogeneities depending on a district's car density (per sqkm) in columns (5.1) to (6.2). The results confirm this notion. Despite a somewhat higher take-up of the policy in low car density regions (5.0 vs 4.5 percent), the effect on NO_2 emissions is stronger in high car-density areas, with an absolute reduction of -1.98 $\mu g/m^3$ compared to -1.47 $\mu g/m^3$.

Jointly these results imply that for the evaluation of car scrappage schemes, it does not only matter where the incentives to replace cars are strongest, but also whether there are heterogeneities in the impact of each replaced car on emissions and thus on local air quality. We show below that this spatial heterogeneity in absolute emission reductions also has implications for the distribution of health benefits, which lends support to more tailored clean air policies targeted at urban areas.

8 Discussion: Cost-Benefit Implications

Our empirical estimates allow us to conduct a simple cost-benefit analysis of the German environmental premium. To this end, we combine our estimates of air quality improvements with existing estimates from the literature on the health impacts of exposure to air pollution. We focus on reductions in long-term mortality attributable to lower NO_2 concentrations as our measure of benefits.[38] Given that there are likely policy-induced effects on other outcomes, our estimates should be viewed as lower bound estimates of the full benefit of enhanced air quality.[39]

To estimate the effects of NO_2 reduction on long-term mortality we use concentration response functions that relate pollution exposure to mortality risk following Fowlie et al. (2019) and Carozzi and Roth (2019). Assuming a log-linear relationship between concentration exposure and mortality risk, the change in deaths caused by a change in NO_2 can then be expressed as

$$\Delta Deaths = Pop_{2008} \cdot m_{2008} \cdot \left[1 - exp\left(-\gamma \cdot \Delta NO_2\right)\right], \quad (5)$$

where Pop_{2008} measures the German population in 2008, m_{2008} is the 2008 baseline mortality incidence rate (10.3 per 1,000 inhabitants) and γ measures the average effect of an increase in NO_2 by 1 $\mu g/m^3$ on all-cause mortality. We do not have a direct estimate for γ. γ can however be easily derived using information on relative mortality risk (RR), as $\gamma = \frac{ln(RR)}{\Delta NO_2}$. We take the relative risk ratio from Atkinson et al. (2018), who estimate a ratio of 1.023 per 10 $\mu g/m^3$ based on a meta-analysis of studies in the epidemiology literature.[40] This implies that $\gamma = 0.0023$. To provide a conservative benefit assessment, we focus on our NO_2 reduction estimate of 0.79 $\mu g/m^3$ (with a 95 percent CI of [0.26$\mu g/m^3$, 1.31 $\mu g/m^3$]) from the pooled first difference specification (Table 2, Column 4). This yields an estimate of about 1,515 (95 percent CI of [513, 2550]) deaths avoided by the policy annually.[41]

[38] We ignore acute mortality due to short-term changes in NO_2, since it is likely to measure harvesting effects, i.e. the phenomenon that those who die from pollution exposure are near death anyway.

[39] The literature has for example shown effects of reduced air pollution on morbidity (Deschenes et al. (2017)), labor supply (Hanna and Oliva (2015)), productivity (Graff Zivin and Neidell (2012)), cognition (Ebenstein et al. (2016)) or the social costs of avoidance behavior (Moretti and Neidell (2011)).

[40] This RR is recommended by the Committee on the Medical Effects of Air Pollutants (COMEAP (2018)) if taking NO_2 as a marker for the pollutant mixture to assess the health benefits of interventions that affect a mixture of traffic-related pollutants.

[41] The CI assumes that there is only uncertainty in the estimates of NO_2 effects.

The value of a statistical life (VSL) can be used to assign a monetary value to these avoided deaths. We apply an income-adjusted VSL estimate for Germany of 4.32 million EUR per life (7.9 million USD, see Viscusi and Masterman (2017)). This implies an annual monetary value of deaths averted by the German environmental premium of 6.5 (95 percent CI of [2.2, 11.0]) billion EUR using our baseline pooled estimate or 80 (95 percent CI of [27, 134]) EUR per capita.

To provide an estimate of total health benefits of the policy, we assume that the effects on air quality last for at least four years. This is in line with our findings that in this period estimated effects on NO_2 are relatively stable (see Figure 10). Conservatively assuming no health benefits afterwards and a social discount rate of 6 percent, the total discounted health benefits are 22.7 (95 percent CI of [7.7, 38.2]) billion EUR. These benefits exceed the policy cost of 5 billion EUR, indicating that the health benefits of the policy-induced improvement in local air quality are economically important.[42]

Our spatial heterogeneity findings indicate that the total benefits of the policy may be spatially unevenly distributed. To illustrate this, we now discuss how health benefits are distributed across rural and urban areas. As shown in Section 7, NO_2 reductions are larger in urban than in rural areas. When using the pooled first difference specification, reductions amount to 0.90 $\mu g/m^3$ and 0.66 $\mu g/m^3$, respectively.[43] This suggests about 1,180 averted deaths with a value of 5.1 billion EUR (or 132 EUR per capita) annually in urban areas alone, implying that 77 percent of all averted death and health benefits accrue to urban areas.[44] This finding lends support that clean air policies targeted at cities, such as low-emission zones or congestion pricing, are targeting areas with high policy benefits (Wolff 2014; Gehrsitz 2017; Pestel and Wozny 2019).

9 Conclusion

This paper shows that car scrappage schemes can be successful in rejuvenating the car fleet and have substantial effects on local air quality by studying the "environmental premium" - a large car scrappage scheme introduced in Germany in 2009. The scheme provided incentives for consumers to buy new cars by providing a lump-sum subsidy for each newly purchased car when the buyer at the same time retired an at least 9 years old used car. We find that the policy

[42] The comparison abstracts from potential positive multiplier effects on government spending that motivated the policy.

[43] The corresponding regression estimates estimates are 0.067 $\mu g/m^3$ vs 0.042 $\mu g/m^3$ for each additional clunker per 2005 sales in urban and rural areas, respectively. The weighted average of these effects is close in magnitude to the baseline pooled difference estimates in the full sample of 0.056 $\mu g/m^3$.

[44] Using the event study estimates presented in Table A3 instead, we equivalently estimate a share of 77 percent of health benefits accruing to urban areas.

induced about 1 million additional car purchases, which is equivalent to an increase in purchases of around 70 percent relative to the pre-policy period. While there are windfall gains for around half of all buyers, we do not find evidence that these purchases have been pulled forward from the immediately following years, indicating that the policy was at least temporarily successful in rejuvenating the car fleet. As a consequence, local air quality improved. NO_2 emissions decreased by about 7 percent in the post-policy period, and we find indicative evidence that the policy also reduced PM_{10} emissions. These effects were particularly strong in urban areas with high car density.

Our results partially stand in contrast to the existing literature analyzing car scrappage schemes that has found large and immediate reversals in purchases at the end of the policy. While our study is not able to directly analyze what explains this discrepancy, a potential explanation may be differences in program duration and size. The German program was considerably larger than other existing programs. It had a total budget of 5 billion EUR allowing for a replacement of 4.8 percent or 2 million passenger vehicles and lasted 9 months, suggesting that factors like program duration and size should potentially be taken into account when implementing such a policy.

Are car scrappage schemes an efficient way to reduce local air pollution? Back-of-the-envelope calculations suggest that the mortality benefits stemming from the reductions in NO_2 emissions likely exceed the budgetary costs of the policy. Nevertheless, the subsidy constituted windfall gains for around half of all subsidized buyers. Consequently, the question arises whether other measures may be more cost efficient when aiming to reduce local air pollution. Spatial heterogeneities in the effects suggest that policies targeted at cities may be more efficient. Further, schemes subsidizing (fuel efficient) gasoline cars today may create "lock-in" effects if new technologies (such as electric or hydrogen powered cars) are imminent, as this may lead subsidized customers to postpone the adoption of such alternative technologies in the future.

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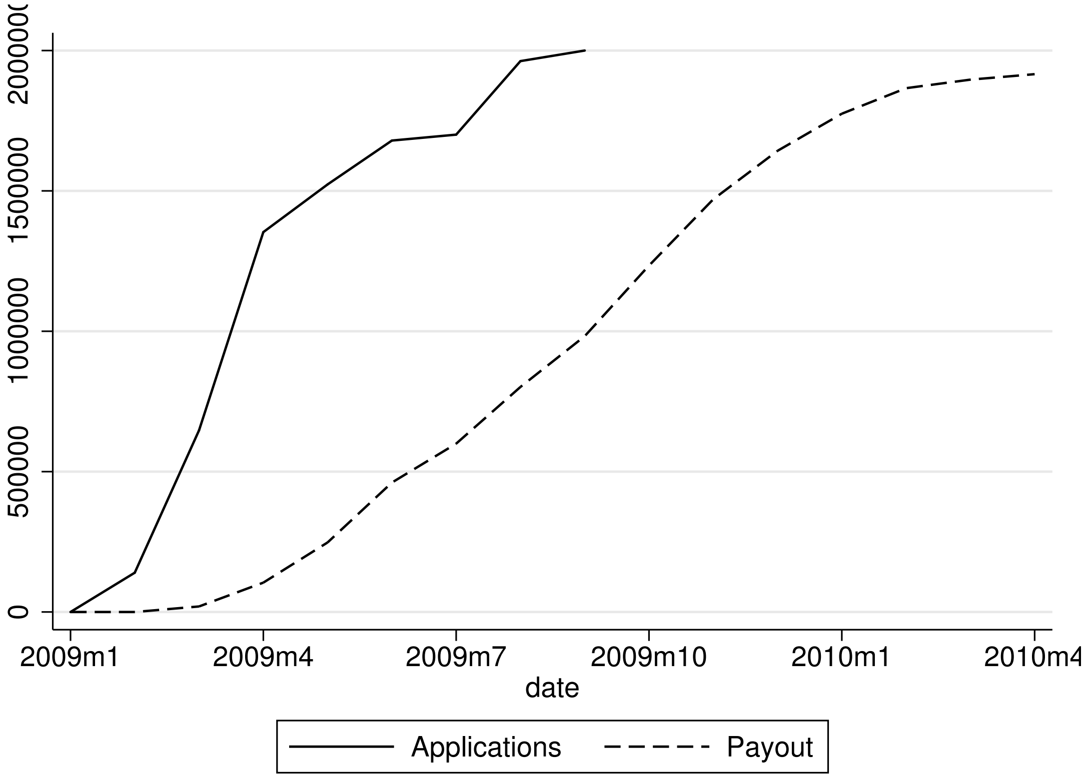
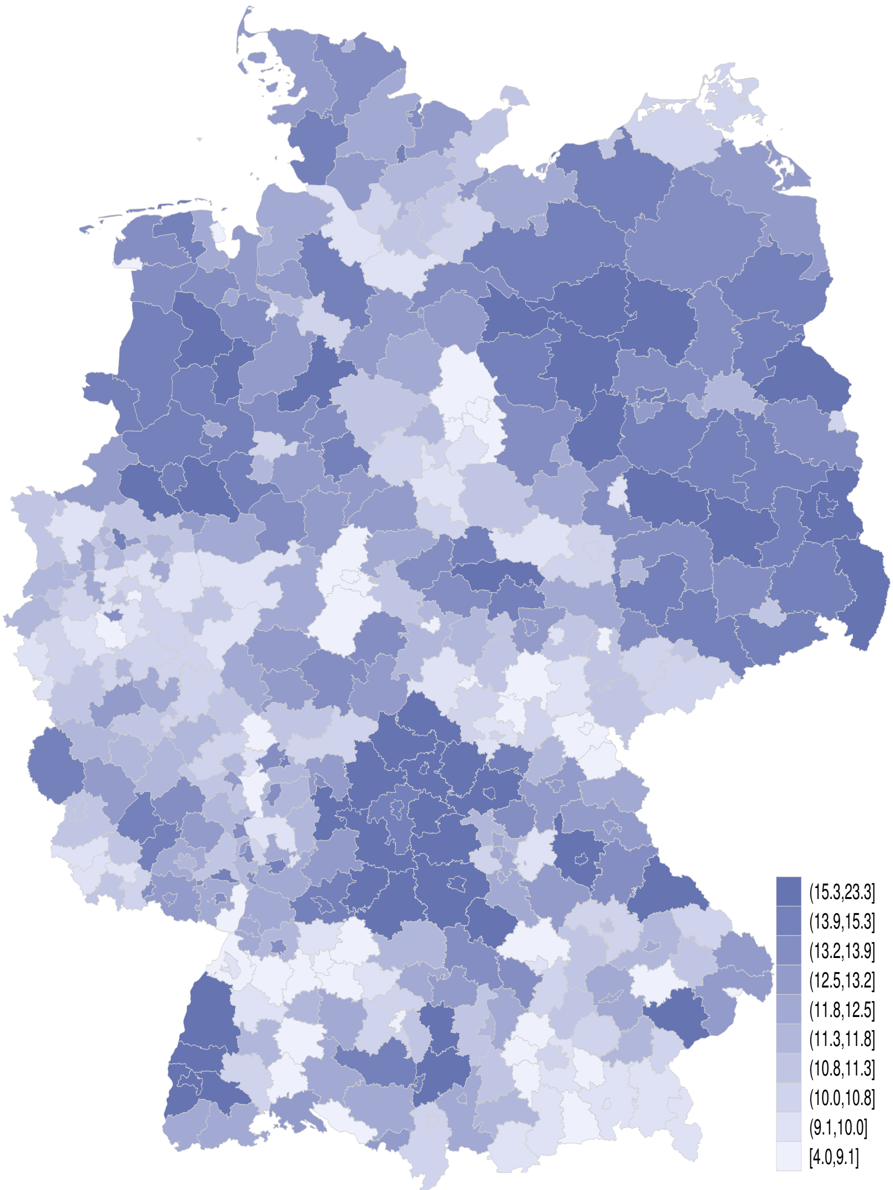
Figures and Tables

Figure 1: Application and Payout Dates



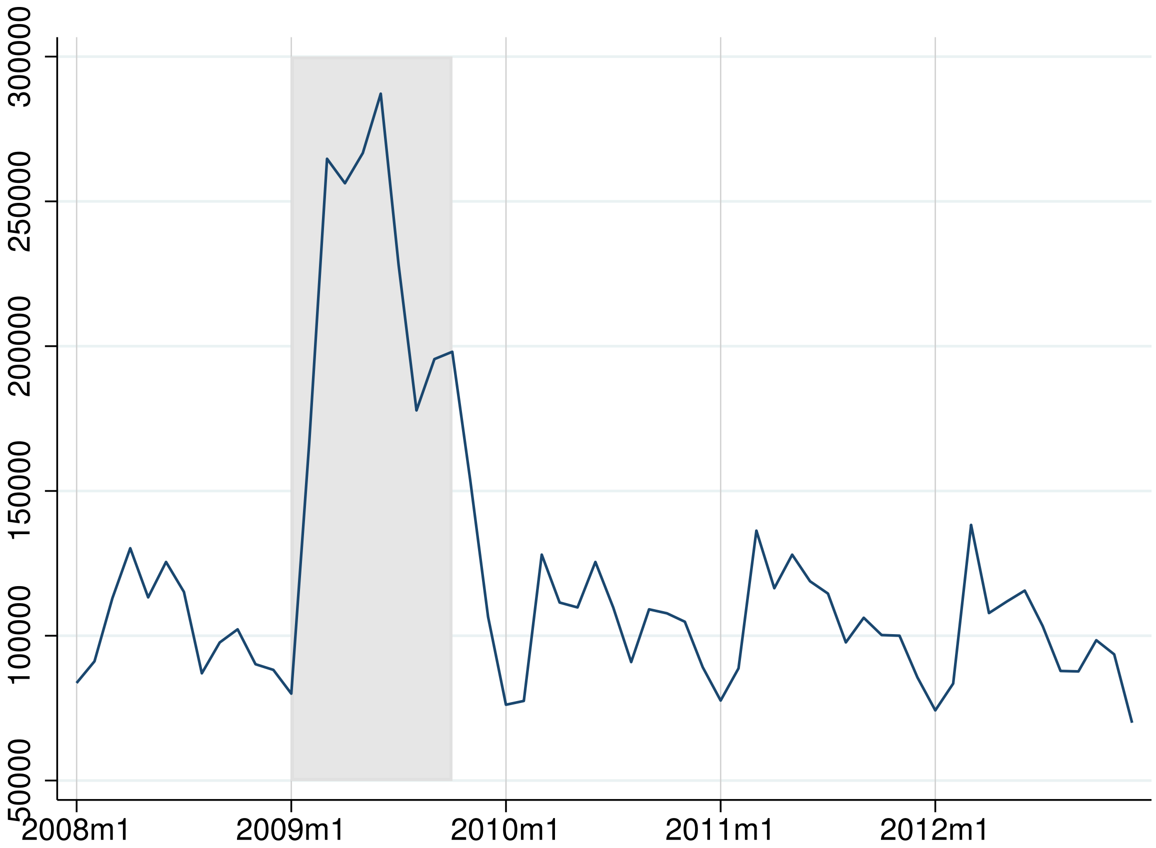
Notes: This figure shows applications for the 2500 EUR subsidy provided by the car scrappage scheme and premium payout dates by month. The data source underlying this figure is the reply of the German government to a "Kleine Anfrage" on June 6 2010, Drucksache 17/2030, Attachment 1.

Figure 2: Regional Distribution of Clunkers by Decile Groups



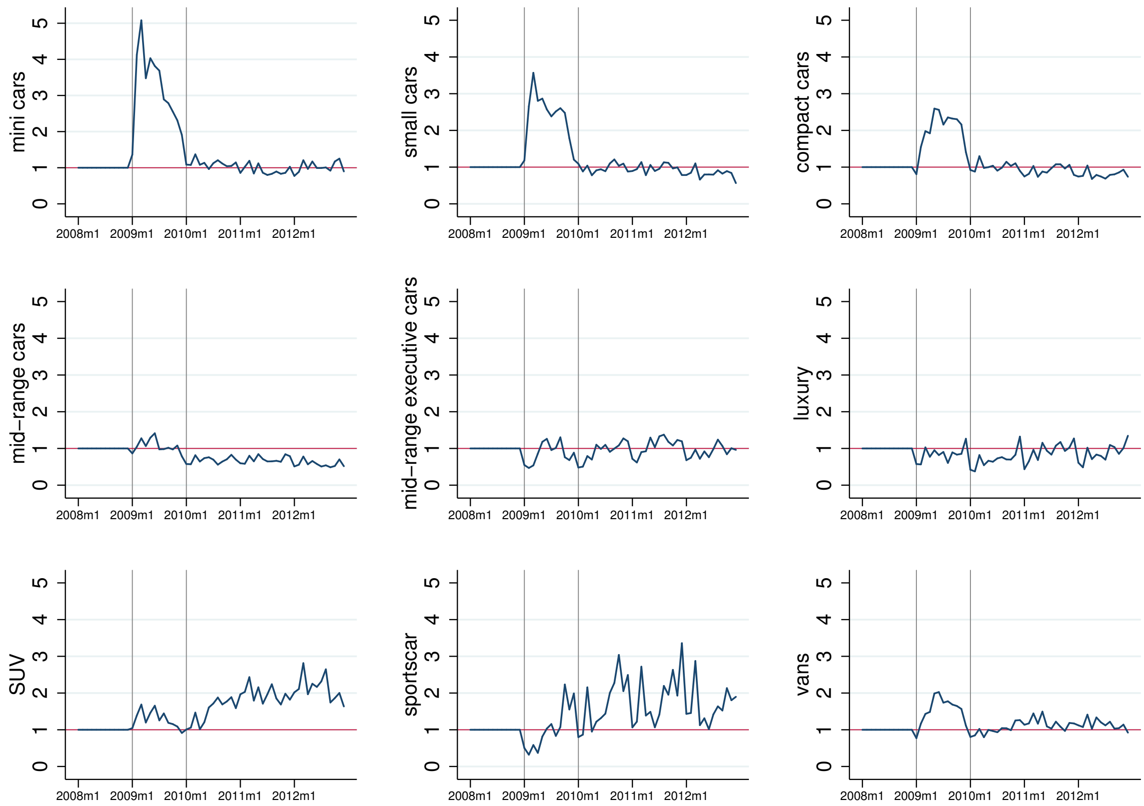
Notes: The figure shows the regional distribution of clunkers per 2005 car purchases as defined in equation (1) by deciles (see legend in lower right corner) across districts in Germany. Darker colors imply a higher level of clunkers for the respective district.

Figure 3: Car Purchases over Time



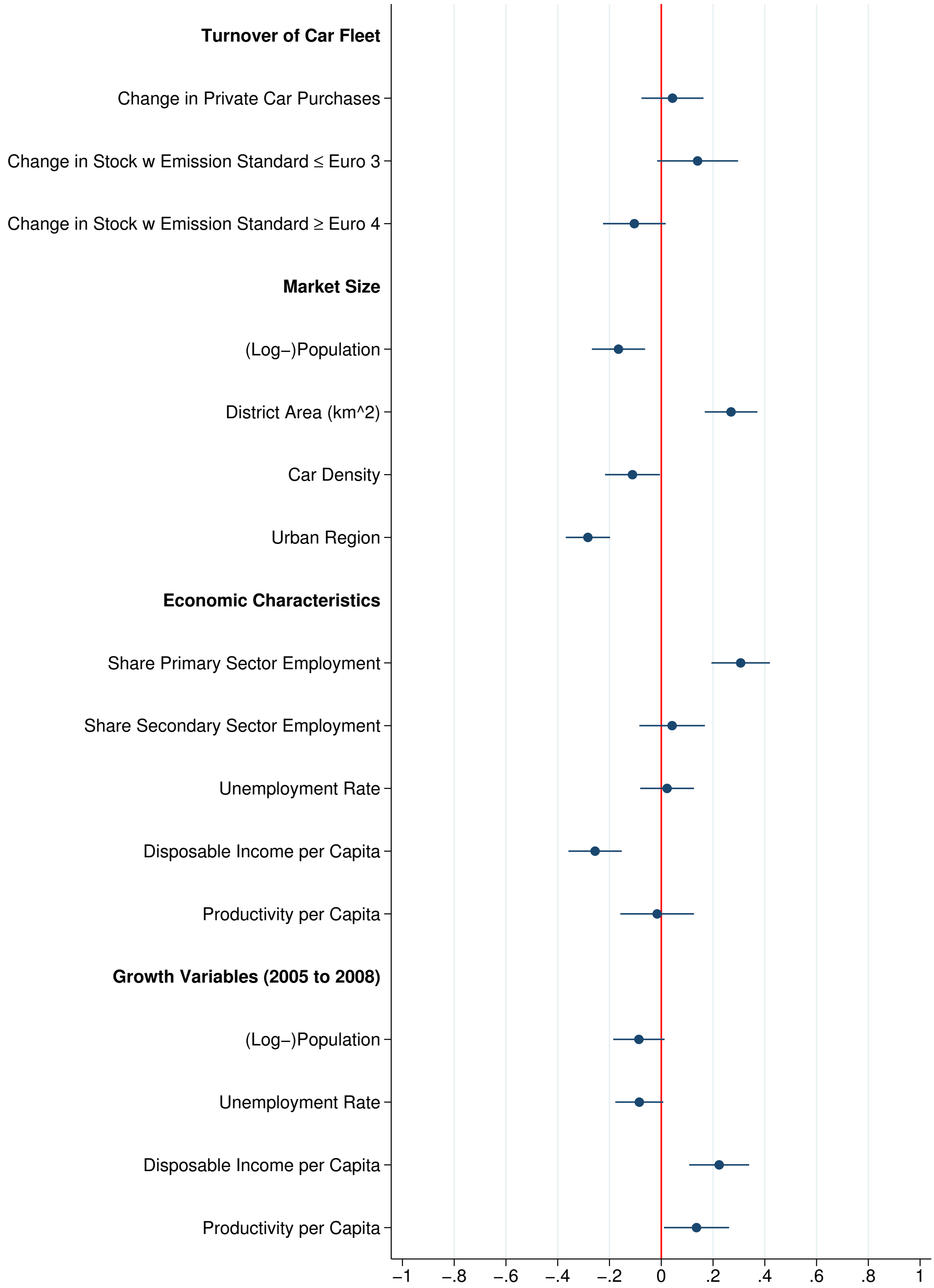
Notes: The figure reports purchases of new private passenger vehicles between 2008 and 2012 by month. New car purchases are defined as registrations of new cars.

Figure 4: Changes in Car Purchases by Segment



Notes: The figure reports the change in purchases of new private passenger cars between 2009 and 2012 by month and segment relative to the corresponding month in 2008. New car purchases are defined as registrations of new cars.

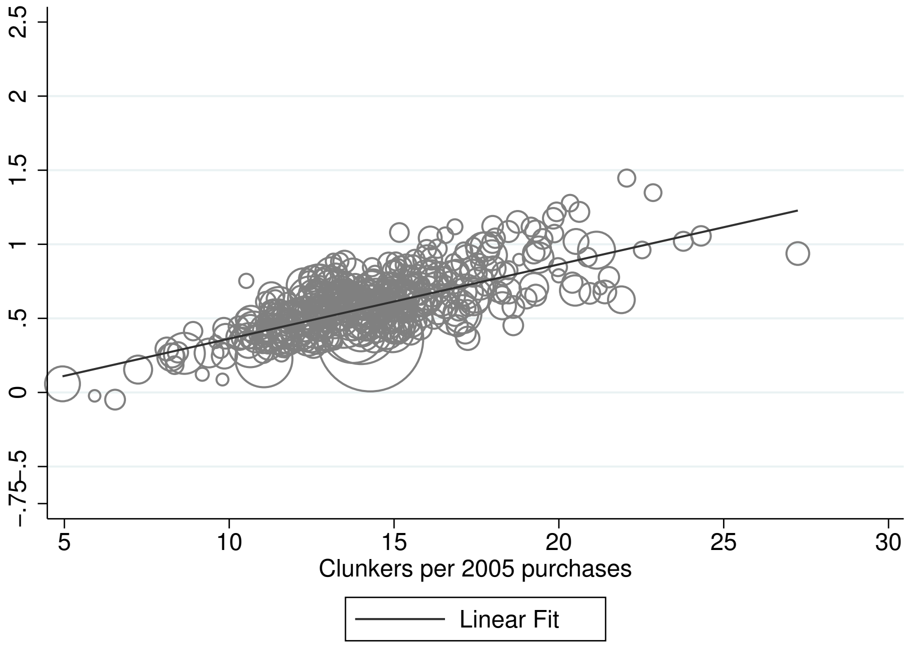
Figure 5: Pre-Treatment Correlations with Clunkers Measure

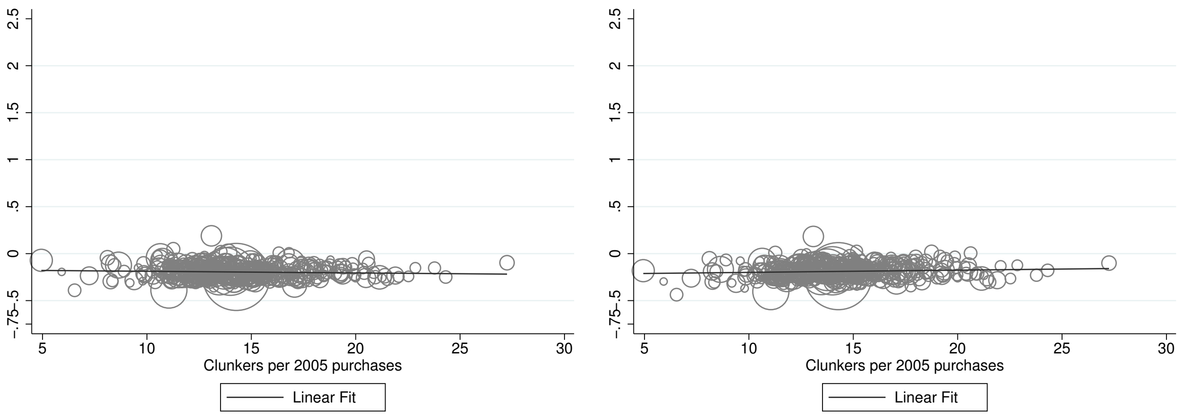


Notes: The figure reports weighted correlation coefficients between the measure of clunkers in a district and pre-treatment levels and growth rates in car market, economic and demographic district characteristics. Growth rates are defined between 2005 and 2008. Correlations are measured net of federal state fixed effects. The clunkers measure is defined as the number of clunkers in a district at the beginning of January 2009 normalized by private car purchases in 2005. The horizontal bars show the 95% confidence interval based on standard errors clustered at the district level.

Figure 6: Relationship between Clunkers and Changes in Car Purchases

(a) Year of Car Scrappage Scheme (2009)





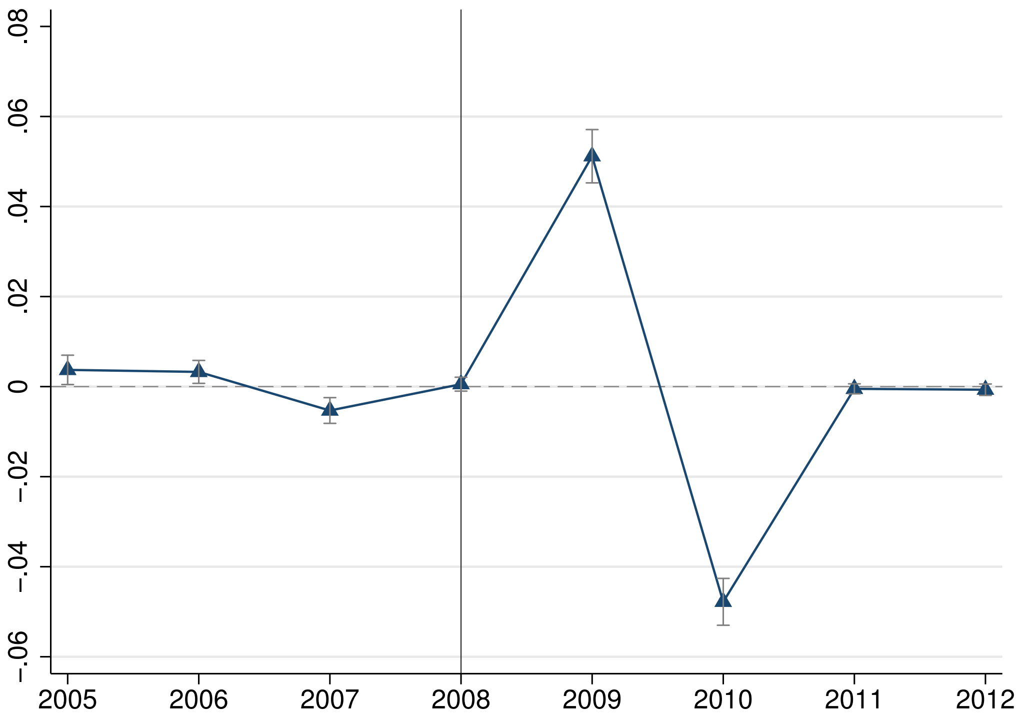
(b) Year before Car Scrappage Scheme (2008)

(c) Year after Car Scrappage Scheme (2010)

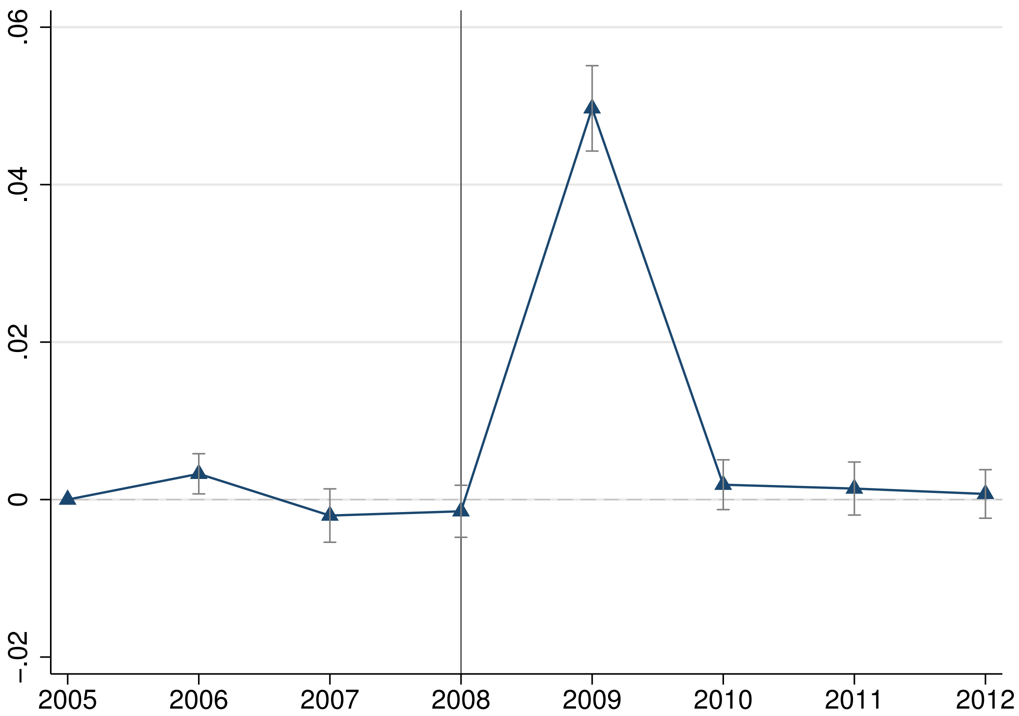
Notes: The figure plots the change in new car purchases (relative to 2005 purchases) against the measure of clunkers in a district for the year in which the car scrappage scheme was implemented (2009, sub-figure (a)), the year before the implementation (2008, sub-figure (b)) and the year after the implementation (2010, sub-figure (c)). The measure of clunkers in a region is defined as clunkers per 2005 car purchases as described in Section (4.1). Observations are measured at the district level. The size of each circle is proportional to district level population in 2008 and OLS is weighted by population in 2008.

Figure 7: The Effects on Car Purchases

(a) Year-by-Year Changes



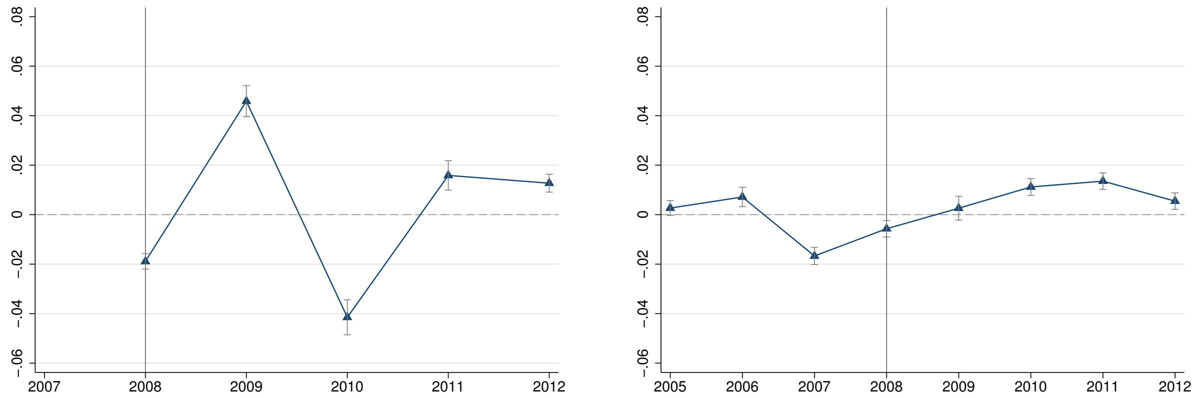
(b) Changes relative to 2005



Notes: The figure plots coefficient estimates and 95-percent confidence intervals of the effects of the car scrappage scheme on new car purchases based on equation (2), controlling for federal state x year fixed effects and market size controls. The underlying regressions are weighted by district population in 2008. In sub-figure (a), the dependent variable is the change in car purchases between year $t-1$ and t normalized by 2005 car purchases (see Section 4.2) and hence the coefficients represent year-by-year effects. In sub-figure (b), we present effects relative to 2005 by adding up the year-by-year effects over time. This is equivalent to estimating a specification with the change in purchases between 2005 and t as the dependent variable. The coefficient estimates in Figure 7(b) correspond to the estimates in Table A2, column (1). Standard errors are clustered at the district level.

Figure 8: Ownership Changes and Deregistrations (Year-by-Year Changes)

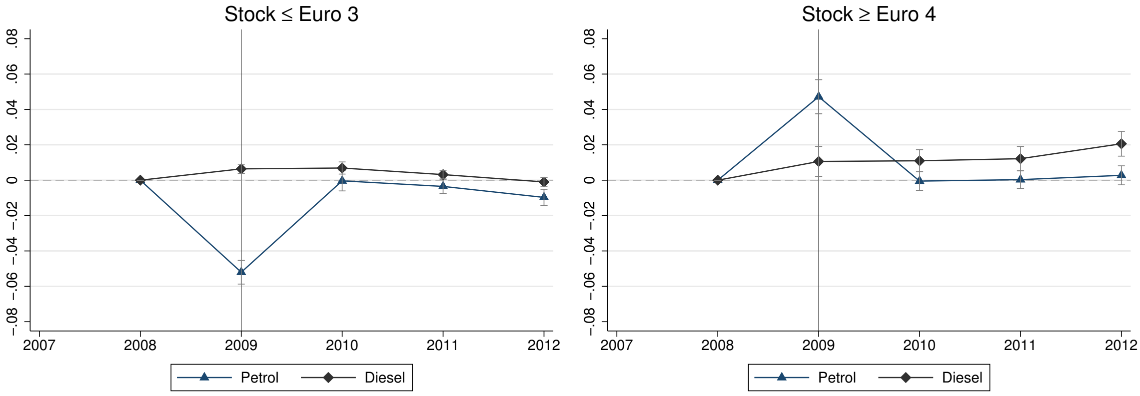
(a) Deregistrations (b) Ownership Changes



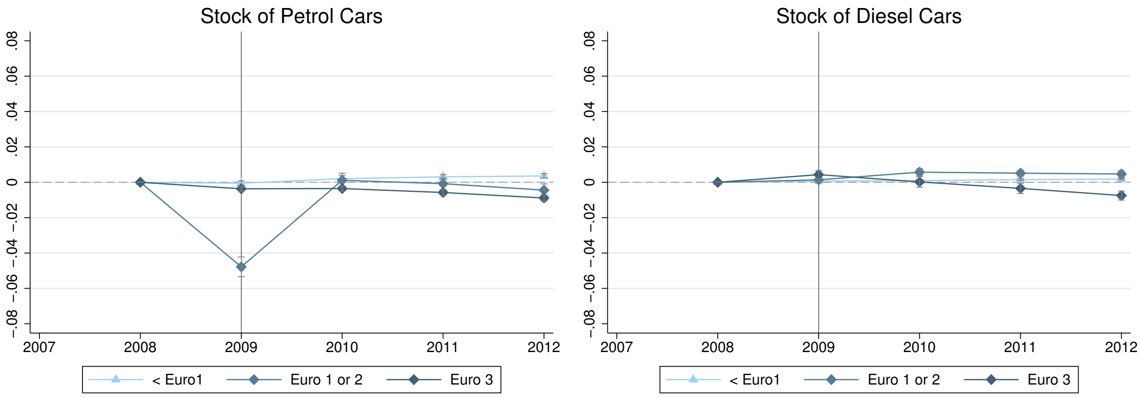
Notes: The figure plots coefficient estimates and 95-percent confidence intervals of the effects of the car scrappage scheme on deregistrations in sub-figure (a) and on ownership changes in sub-figure (b). Estimations are based on equation (2), controlling for federal state x year fixed effects. The dependent variable is the change in the respective outcome variable between year $t-1$ and t normalized by 2005 car purchases (see Section 4.2) and hence the coefficients represent year-by-year effects. The underlying regressions are weighted by district population in 2008. Standard errors are clustered at the district level.

Figure 9: Composition of Stock (Year-by-Year Changes)

(a) Stock of High vs Low Emission Cars



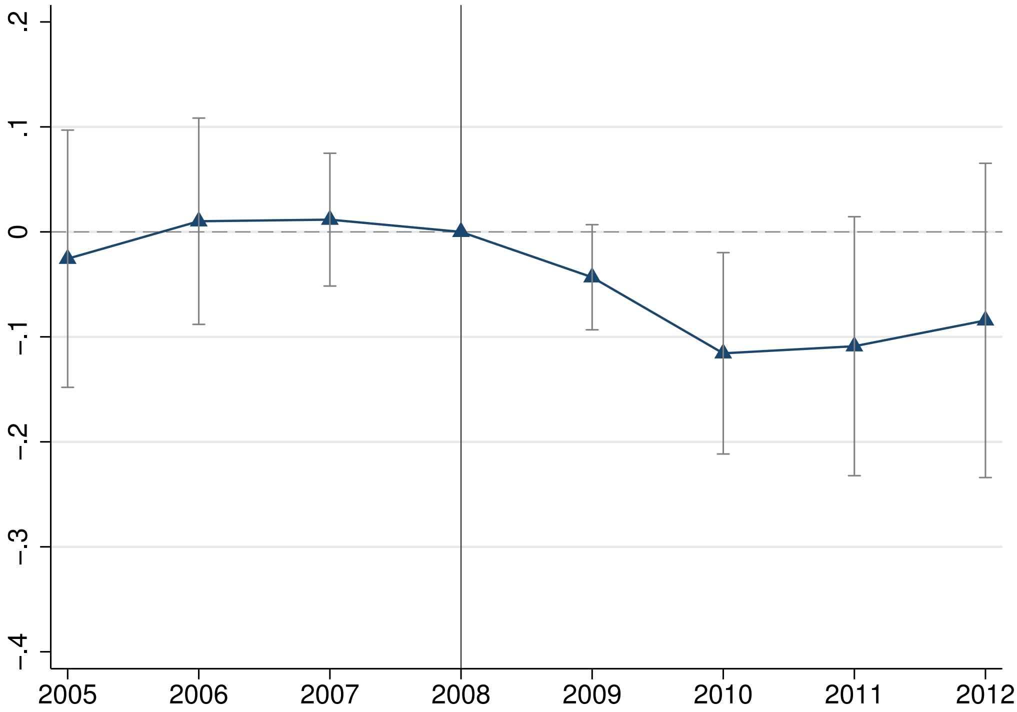
(b) Detailed Decomposition of High Emission Car Stock



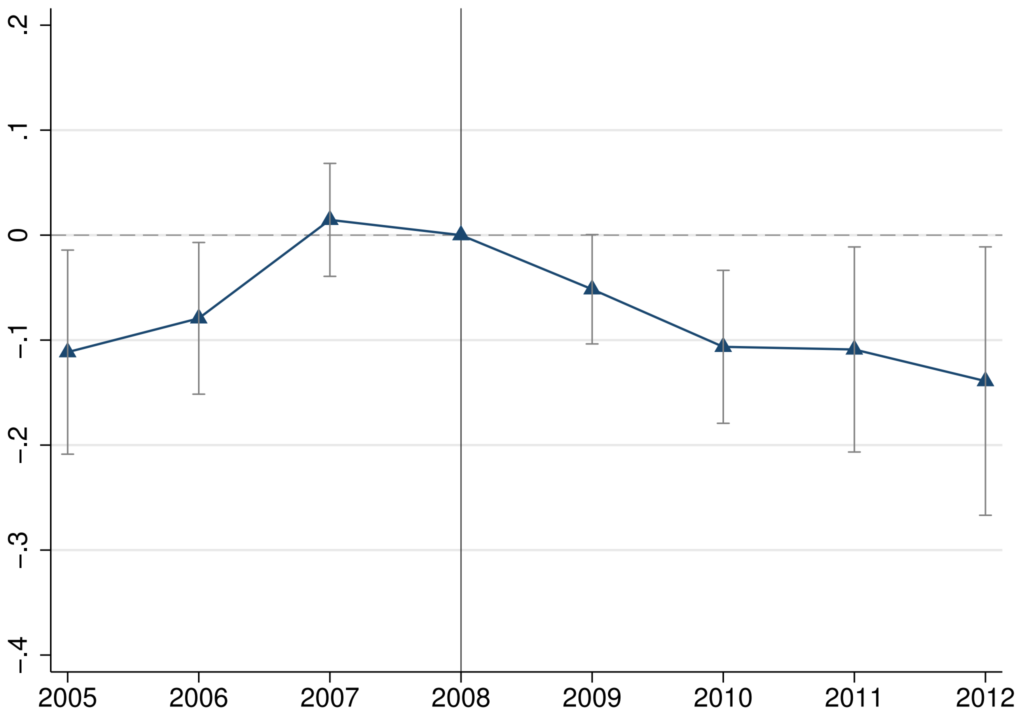
Notes: The figure plots coefficient estimates and 95-percent confidence intervals of the effects of the car scrappage scheme on the stock of cars by emission standard. Estimations are based on equation (2), controlling for federal state x year fixed effects and district fixed effects. The dependent variable is the change in the respective outcome variable between year $t-1$ and t normalized by 2005 car purchases (see Section 4.2) and hence the coefficients represent year-by-year effects. The underlying regressions are weighted by district population in 2008. Standard errors are clustered at the district level.

Figure 10: The Effects on Emissions - Cumulative Effects

(a) NO2



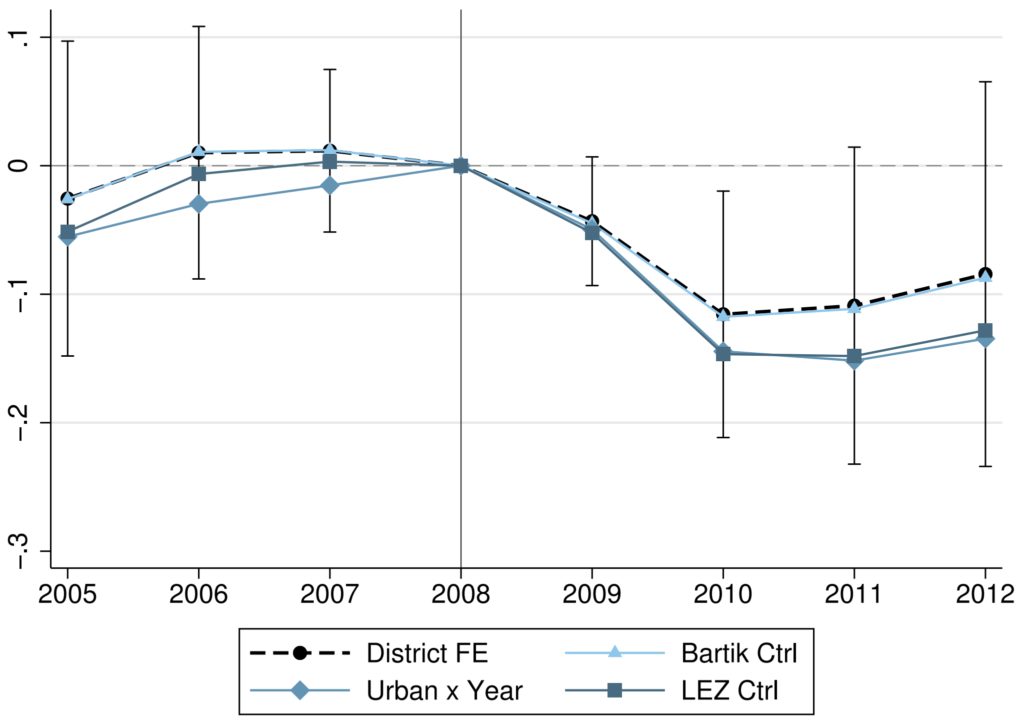
(b) PM10



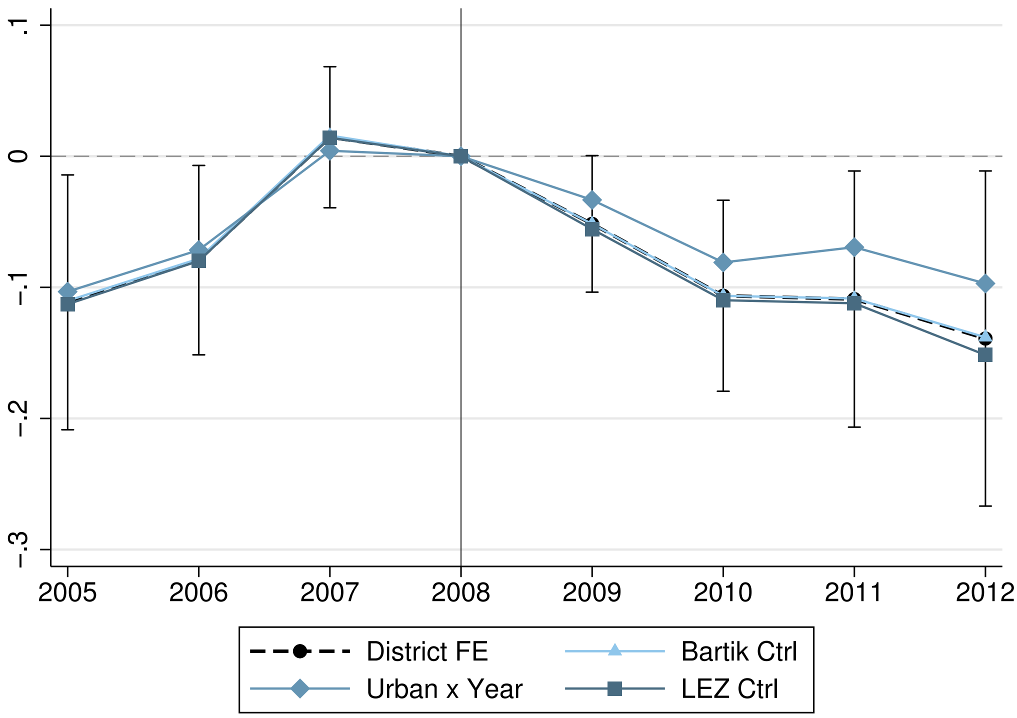
Notes: The figure plots coefficient estimates and 95-percent confidence intervals of event-study regressions of the effects of the environmental premium on emission concentrations based on variants of equation (4), controlling for federal state x year fixed effects, district fixed effects and yearly changes in weather conditions. The figure plots the cumulative effects of the car scrappage scheme on NO_2 emissions in sub-figure (a) (based on the year-by-year effects presented in Table A3, column (1)) and on PM_{10} emissions in sub-figure (b) (based on the year-by-year effects presented in Table A3, column (4)). The underlying regressions are weighted by district population in 2008. Standard errors are clustered at the district level.

Figure 11: The Effects on Emissions - Robustness II (Cumulative Effects)

(a) NO2



(b) PM10



Notes: The figure plots coefficient estimates and of event-study regressions of the effects of the environmental premium on emission concentrations based on variants of equation (4), controlling for federal state x year fixed effects, district fixed effects and yearly changes in weather conditions. The figure plots the cumulative effects of the car scrappage scheme on NO_2 emissions in sub-figure (a) (equivalent to Table A3, column (1)) and on PM_{10} emissions in sub-figure (b) (equivalent to Table A3, column (4)). The underlying regressions are weighted by district population in 2008. The 95 percent confidence interval is plotted for the baseline specification including district fixed effects only. Standard errors are clustered at the district level. The remaining standard errors can be found in Table A3.

Table 1: Summary Statistics: Regional Characteristics

	mean	sd	p10	p50	p90
Panel A: Clunker Measures					
Clunkers					
Clunkers (Jan 2009)	43674	37487	15977	34219	75697
Clunkers per 2005 purchases	14.1	2.72	11.2	14	17.4
Clunkers per capita	0.256	0.0364	0.199	0.263	0.296
Panel B: Car Registrations and Emissions					
Private Car Registrations (2008)					
New Car Purchases	3085	2856	1081	2316	5410
Owner Changes	14335	12195	5418	11251	25117
Deregistrations	14342	11399	5549	11483	24691
Local Emissions (2008)					
NO2 concentration (µg/m^3)	16.7	5.96	10.6	15.1	26.7
PM10 concentration (µg/m^3)	17.5	2.62	14.3	17.2	21.1
SO2 concentration (µg/m^3)	3.42	2.14	1.72	2.84	5.49
Panel C: Demographic and Economic Characteristics					
Levels (2008)					
Population	204278	230185	74958	149917	350866
Unemployment Rate	7.45	3.48	3.44	6.7	12.7
Disposable Income per Capita	18768	2379	15896	18539	21674
Productivity per Capita	27	11	16.9	24.4	44.6
Growth Rates (2005 to 2008)					
Population Change	-0.004	0.015	-0.025	-0.003	0.014
Unemployment Rate Change	-3.66	1.22	-5.2	-3.52	-2.19
Disposable Income Change	0.065	0.0216	0.0388	0.0639	0.0893
Productivity Growth	0.107	0.0545	0.0443	0.108	0.173

Notes: The table reports the mean, standard deviation and the 10th, 50th and 90th percentile for various clunkers measures in Panel A, for pre-policy levels of private car registrations and local pollutant concentrations in Panel B, and for various demographic and economic characteristics in Panel C. Clunkers are defined as all registered cars with emission standard Euro 2 or older. New car purchases are defined as new registrations of private passenger cars. Productivity is measured as gross value added per capita. All variables are measured at the district level and observations are weighted by 2008 district level population, except for population itself which is unweighted.

Table 2: The Effects on Emissions - First Differences

	NO2 Growth				PM10 Growth			
	Base Controls	add Economic Controls	add Pre-Trends (Econ.)	add Weather Controls	Base Controls	add Economic Controls	add Pre-Trends (Econ.)	add Weather Controls
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variable of Interest								
Clunkers per 2005 purchases	-0.050***	-0.052***	-0.056***	-0.056***	-0.018	-0.006	-0.01	-0.015
	(0.019)	(0.019)	(0.019)	(0.019)	(0.015)	(0.014)	(0.013)	(0.013)
Market Size Controls (measured in 2008)								
(Ln-)Population	-0.773***	-0.621***	-0.538***	-0.528***	-0.133*	-0.056	-0.1	-0.065
	(0.163)	(0.157)	(0.151)	(0.153)	(0.076)	(0.083)	(0.089)	(0.081)
District Area (km^2)	0.001***	0.001***	0.000***	0.000***	0.000**	0.000*	0.000**	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Car Density	-0.002	-0.004***	-0.004***	-0.004**	-0.001	-0.001	0	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Economic Characteristics (measured in 2008)								
Share Primary Sector Empl. (x100)		0.036	0.03	0.034		-0.049	-0.061*	-0.045
		(0.033)	(0.036)	(0.035)		(0.030)	(0.032)	(0.029)
Share Secondary Sector Empl. (x100)		0.004	0	-0.002		0.012*	0.013**	0.007
		(0.008)	(0.008)	(0.009)		(0.006)	(0.006)	(0.006)
Unemployment Rate (x100)		-0.170***	-0.194***	-0.190***		0.021	0.044	0.059*
		(0.036)	(0.045)	(0.045)		(0.027)	(0.031)	(0.032)
Disposable Income per Capita		-0.000**	-0.000**	-0.000***		0	0	0
		(0.000)	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)
Productivity per Capita		0.001	0.004	0.005		-0.008	-0.012*	-0.009
		(0.007)	(0.008)	(0.008)		(0.006)	(0.007)	(0.007)
Growth Variables (2005 to 2008 change)								
Population Growth			-5.942	-5.586			8.290*	9.437**
			(7.423)	(7.468)			(4.706)	(4.657)
Unemployment Rate Growth			0.006	0.01			-0.035	-0.002
			(0.065)	(0.065)			(0.042)	(0.043)
Disposable Income per Capita Growth			4.783*	5.020*			1.277	1.965
			(2.820)	(2.832)			(2.133)	(1.995)
Productivity per Capita Growth			-0.504	-0.455			0.913	1.166*
			(1.037)	(1.042)			(0.648)	(0.685)
Weather Controls (pre/post-policy change)								
Change in Average Temperature				0.1				-0.485
				(0.581)				(0.375)
Change in Annual Precipitation				-0.001				-0.005***
				(0.002)				(0.001)
Federal State FE	x	x	x	x	x	x	x	x
R2	0.672	0.702	0.705	0.706	0.493	0.511	0.517	0.547
N	400	400	400	400	400	400	400	400

Notes: The table reports estimates of pooled first difference regressions of the effects of the environmental premium on emission concentrations based on variants of equation (3). Observations are pooled over two 4-year periods in the pre- and post-policy period respectively (i.e. from 2005 to 2008 and 2009 to 2012). The dependent variable in columns (1) to (4) is the change in NO_2 emissions over the pooled pre- and post-policy period and in columns (5) to (8) the change in PM_{10} emissions. The control variables are described in more detail in Appendix Table A1. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table 3: The Effects on Emissions - Robustness I

	Panel A: NO2 Growth				
	main specification	only districts with measuring station	exclude production regions	drop East Germany	log dependent variable
	(1)	(2)	(3)	(4)	(5)
Clunkers per 2005 purchases	-0.056***	-0.095***	-0.042**	-0.063***	-0.002**
	(0.019)	(0.028)	(0.019)	(0.021)	(0.001)
Federal State FE	x	x	x	x	x
Market Size Controls (2008)	x	x	x	x	x
Economic Characteristics (2008)	x	x	x	x	x
Growth Variables (2005 to 2008)	x	x	x	x	x
Weather Controls	x	x	x	x	x
R2	0.706	0.748	0.689	0.681	0.623
N	400	211	373	324	400

	Panel B: PM10 Growth				
	main specification	only districts with measuring station	exclude production regions	drop East Germany	log dependent variable
	(1)	(2)	(3)	(4)	(5)
Clunkers per 2005 purchases	-0.015	-0.013	-0.025	-0.028**	-0.001
	(0.013)	(0.019)	(0.016)	(0.014)	(0.001)
Federal State FE	x	x	x	x	x
Market Size Controls (2008)	x	x	x	x	x
Economic Characteristics (2008)	x	x	x	x	x
Growth Variables (2005 to 2008)	x	x	x	x	x
Weather Controls	x	x	x	x	x
R2	0.547	0.566	0.528	0.566	0.546
N	400	211	373	324	400

Notes: The table reports estimates of pooled first difference regressions of the effects of the environmental premium on emission concentrations based on variants of equation (3). Observations are pooled over two 4-year periods in the pre- and post-policy period respectively (i.e. from 2005 to 2008 and 2009 to 2012). The dependent variable in Panel A is the change in NO_2 emissions over the pooled pre- and post-policy period and Panel B the change in PM_{10} emissions. All columns include federal state fixed effects and control for pre-policy market size controls and economic characteristics (measured in 2008), the 2005 to 2008 growth of these variables and pre/post-policy changes in weather conditions. The control variables are described in more detail in Appendix A1. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table 4: The Effects on Emissions - Placebo

	Base Controls (1)	add Economic Controls (2)	add Pre-Trends (Econ.) (3)	add Weather Controls (4)
Clunkers per 2005 purchases	0.001	0.009	0.006	0.005
	(0.009)	(0.009)	(0.009)	(0.009)
Federal State FE	x	x	x	x
Market Size Controls (2008)	x	x	x	x
Economic Characteristics (2008)		x	x	x
Growth Variables (2005 to 2008)			x	x
Weather Controls				x
R2	0.71	0.742	0.745	0.751
N	400	400	400	400

Notes: The table reports estimates of pooled first difference regressions of the effects of the environmental premium on SO_2 emissions based on variants of equation (3). Observations are pooled over two 4-year periods in the pre- and post-policy period respectively (i.e. from 2005 to 2008 and 2009 to 2012). All columns include federal state fixed effects. The other control variables are described in more detail in Appendix A1. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table 5: Spatial Heterogeneities

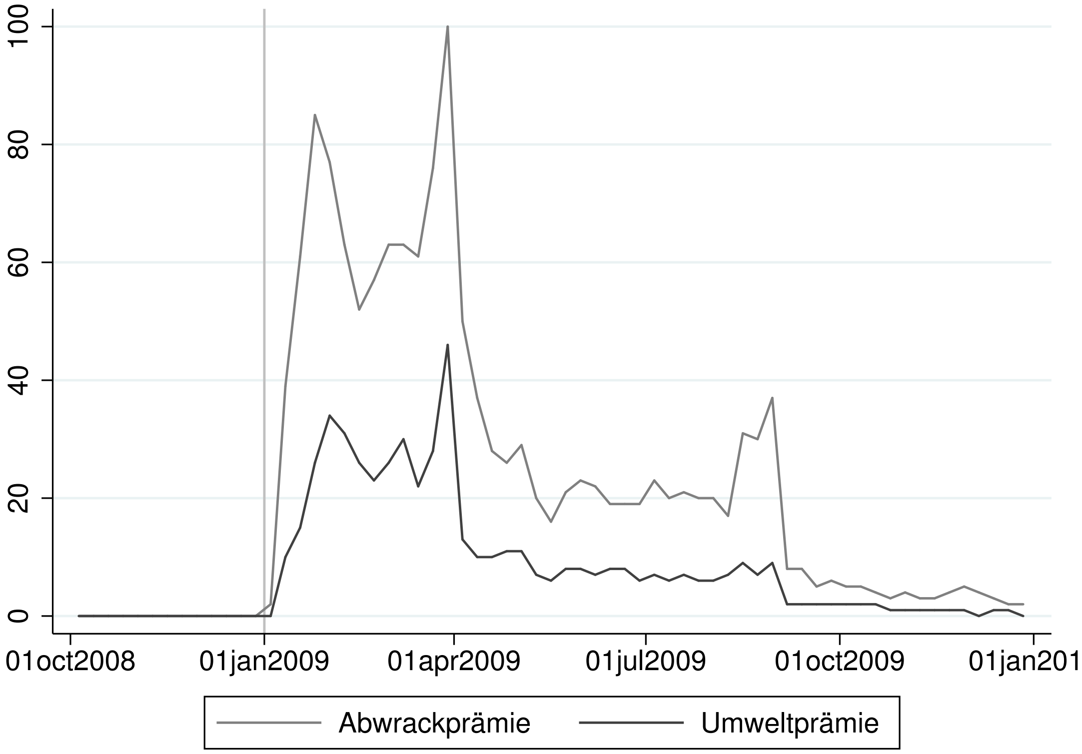
	Population Size				Urban vs Rural				Cars per sq km			
	Car Purchases		NO2 Emissions		Car Purchases		NO2 Emissions		Car Purchases		NO2 Emissions	
	small	large	small	large	rural	urban	rural	urban	low	high	low	high
	(1.1)	(1.2)	(2.1)	(2.2)	(3.1)	(3.2)	(4.1)	(4.2)	(5.1)	(5.2)	(6.1)	(6.2)
Clunkers x 2005			-0.044*	-0.022			-0.035	-0.022			-0.031	-0.003
			(0.024)	(0.025)			(0.024)	(0.027)			(0.024)	(0.027)
Clunkers x 2006	0.004***	0.003**	0.005	-0.012	0.003**	0.003**	-0.002	-0.017	0.003**	0.003**	-0.004	-0.016
	(0.001)	(0.001)	(0.027)	(0.026)	(0.001)	(0.001)	(0.027)	(0.032)	(0.001)	(0.001)	(0.027)	(0.033)
Clunkers x 2007	-0.005***	-0.005***	0.016	0.005	-0.005***	-0.005***	0.011	-0.028	-0.005***	-0.005***	0.003	-0.037
	(0.001)	(0.002)	(0.032)	(0.035)	(0.002)	(0.002)	(0.034)	(0.040)	(0.002)	(0.002)	(0.035)	(0.042)
Clunkers x 2008	0.001	0			0	0			0.001	0.001		
	(0.001)	(0.001)			(0.001)	(0.001)			(0.001)	(0.001)		
Clunkers x 2009	0.053***	0.049***	-0.043*	-0.043	0.051***	0.047***	-0.043*	-0.054*	0.050***	0.045***	-0.044*	-0.046
	(0.003)	(0.003)	(0.025)	(0.027)	(0.003)	(0.003)	(0.026)	(0.030)	(0.003)	(0.004)	(0.026)	(0.030)
Clunkers x 2010	-0.049***	-0.046***	-0.068**	-0.079**	-0.048***	-0.044***	-0.073**	-0.107***	-0.047***	-0.042***	-0.078***	-0.107***
	(0.003)	(0.003)	(0.028)	(0.031)	(0.003)	(0.003)	(0.029)	(0.034)	(0.003)	(0.003)	(0.030)	(0.036)
Clunkers x 2011	0	-0.001	0.014	-0.006	-0.001	0	0.006	-0.012	0	0.001	0.003	-0.014
	(0.001)	(0.001)	(0.022)	(0.022)	(0.001)	(0.001)	(0.022)	(0.024)	(0.001)	(0.001)	(0.021)	(0.025)
Clunkers x 2012	0	-0.001	0.026	0.023	-0.001	0	0.024	0.01	-0.001	0	0.024	0.019
	(0.001)	(0.001)	(0.020)	(0.023)	(0.001)	(0.001)	(0.020)	(0.025)	(0.001)	(0.001)	(0.021)	(0.027)
Clunkers 2008	14.83	13.92			15.57	13.50			15.47	13.40		
NO2 concentration 2008			13.47	17.81			11.62	19.04			11.84	19.48
abs. NO2 reduction (mg/m^3)			-1.05	-1.46			-1.34	-2.20			-1.47	-1.98
R2	0.98		0.62		0.98		0.62		0.98		0.62	
N	3200		3200		3200		3200		3200		3200	

Notes: The table reports estimates of event-study regressions of the effects of the environmental premium on new car purchases and NO_2 emission concentrations based on variants of equations (2) and (4). The dependent variable is the change in the respective outcome variable (car purchases, NO_2 emissions) between year $t-1$ and t (see Section 4.2) and hence the coefficients represent year-by-year effects. In columns (1.1) to (2.2) the sample is split at the median of district population in 2008, in columns (3.1) to (4.2) it is split according to whether a district is classified as rural or urban and in columns (5.1) to (6.2) it is split at the median of the district level of cars per square kilometers in 2008. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Appendix

A Additional Figures and Tables

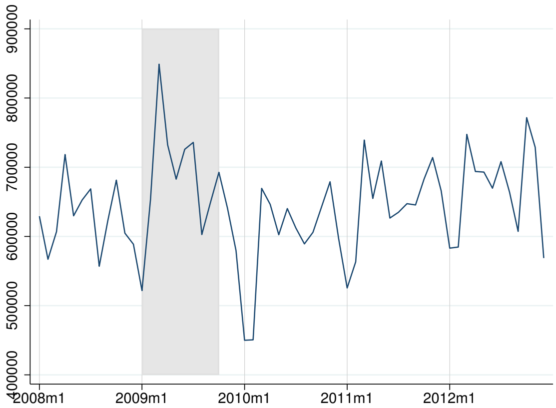
Figure A1: Google Trends Online Searches



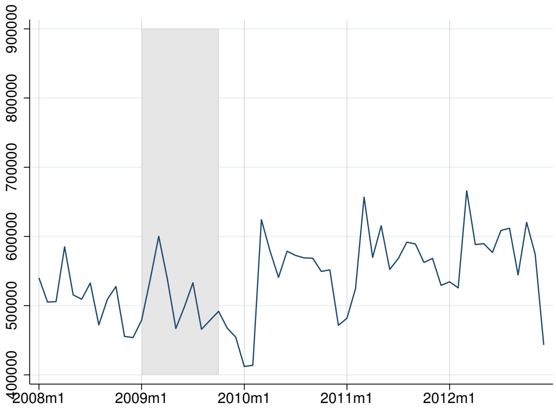
Notes: The figure shows the number of Google searches for the words *Umweltprämie* ("environmental premium"), which was the official name of the car scrappage scheme, and *Abwrackprämie* ("scrappage premium"), under which the scheme was more widely known. Numbers represent search interest relative to the highest point in the graph for Germany between October 2008 and December 2009. A value of 100 reflects the peak popularity of the search terms during that time period. A value of 50 means that the search term is half as popular as during the peak period. The data underlying this figure comes from Google Trends.

Figure A2: Deregistrations and Owner Changes over Time

(a) Deregistrations

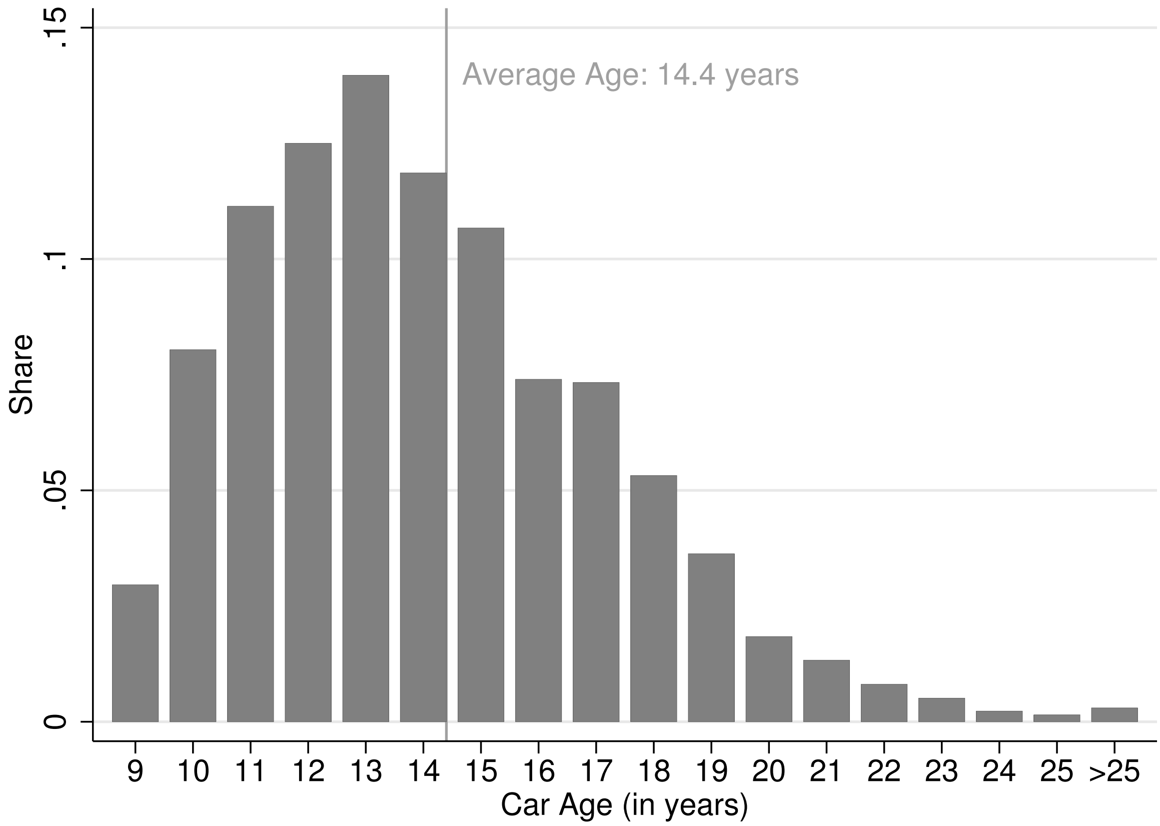


(b) Ownership Changes



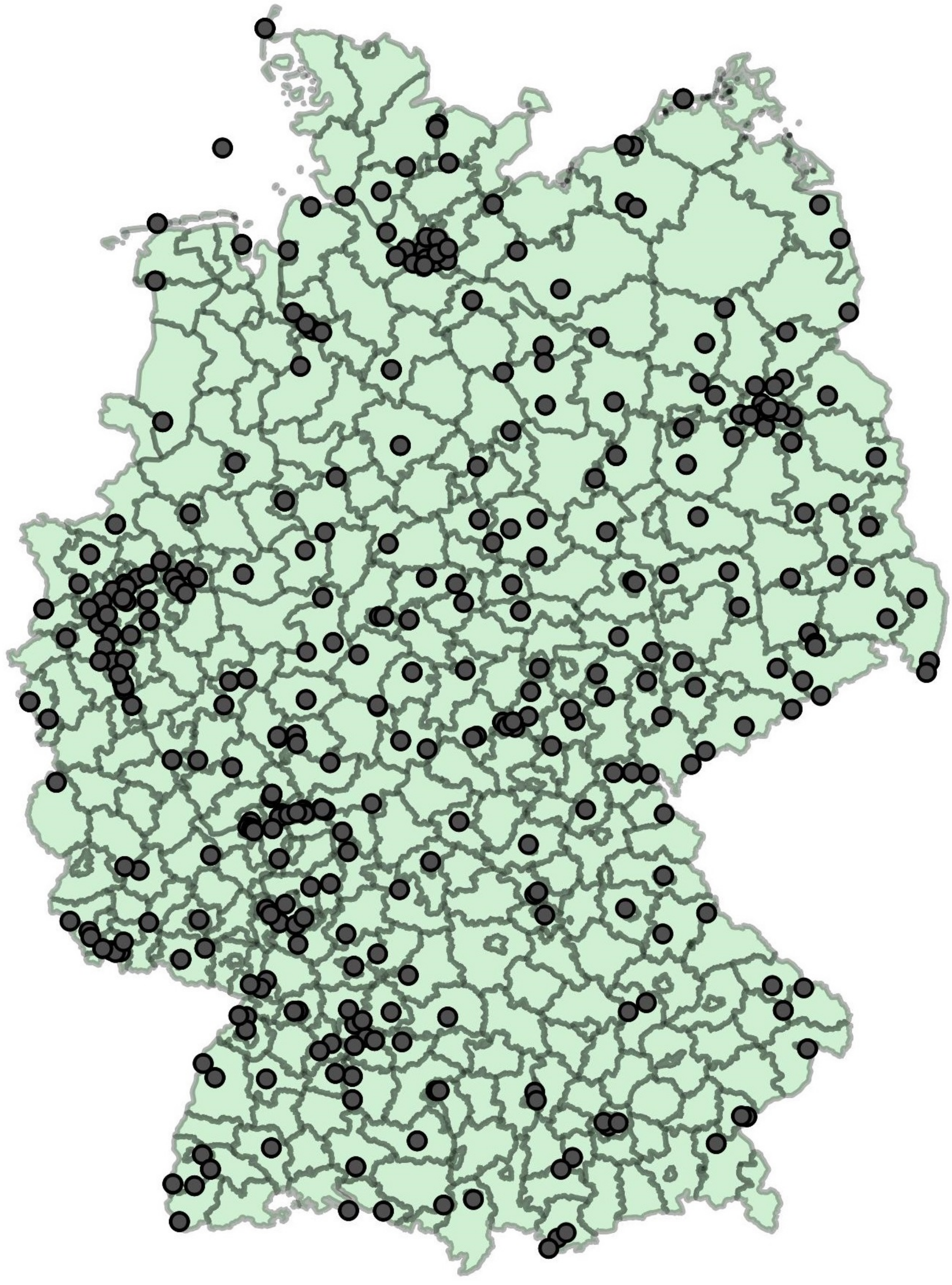
Notes: The figure reports deregistrations and ownership changes of passenger vehicles (both private and business-owned) between 2008 and 2012 by month.

Figure A3: Age Distribution of Scrapped Cars



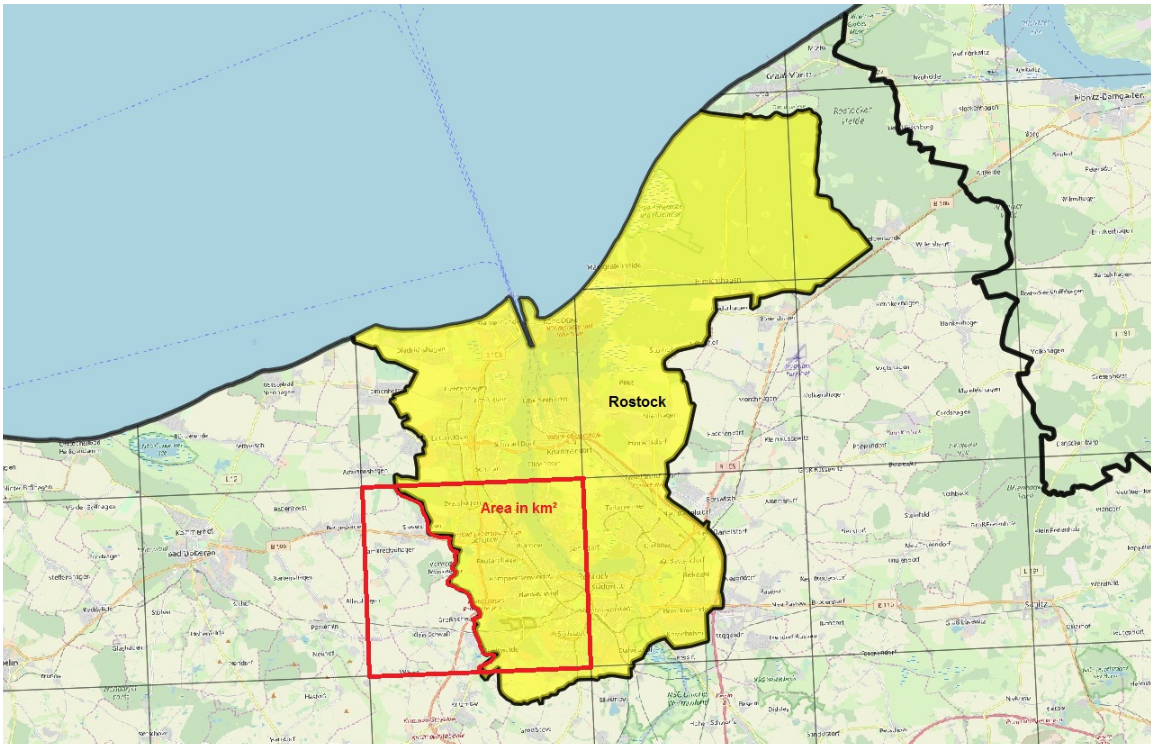
Notes: The figure reports the share of cars scrapped during the car scrappage scheme by car age. The data source underlying this figure is the reply of the German government to a "Kleine Anfrage" on June 6 2010, Drucksache 17/2030, Attachment 2.

Figure A4: Point Source Measuring Stations for PM_{10} and NO_2 in Germany



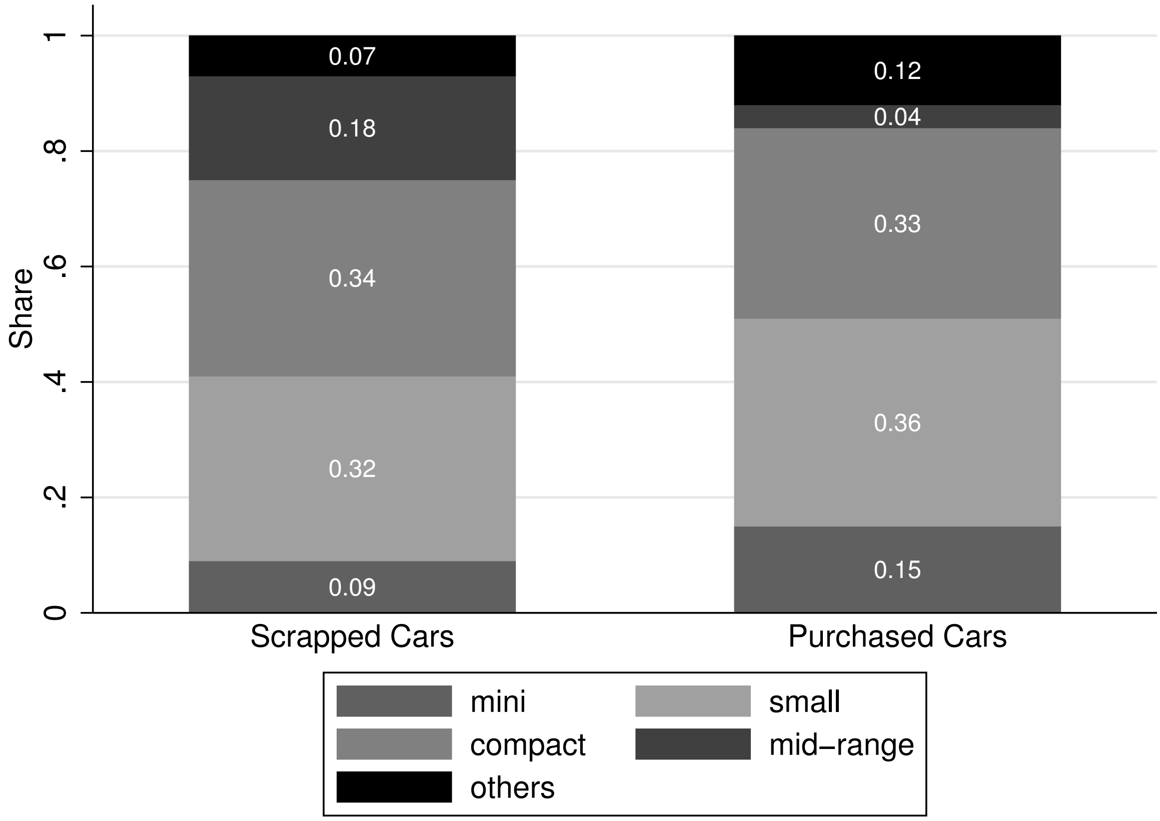
Notes: The map depicts the locations of the 335 background point source measuring stations reporting local NO_2 and PM_{10} concentrations in the years 2005 to 2012.

Figure A5: Spatial Aggregation of Pollution Concentration Data



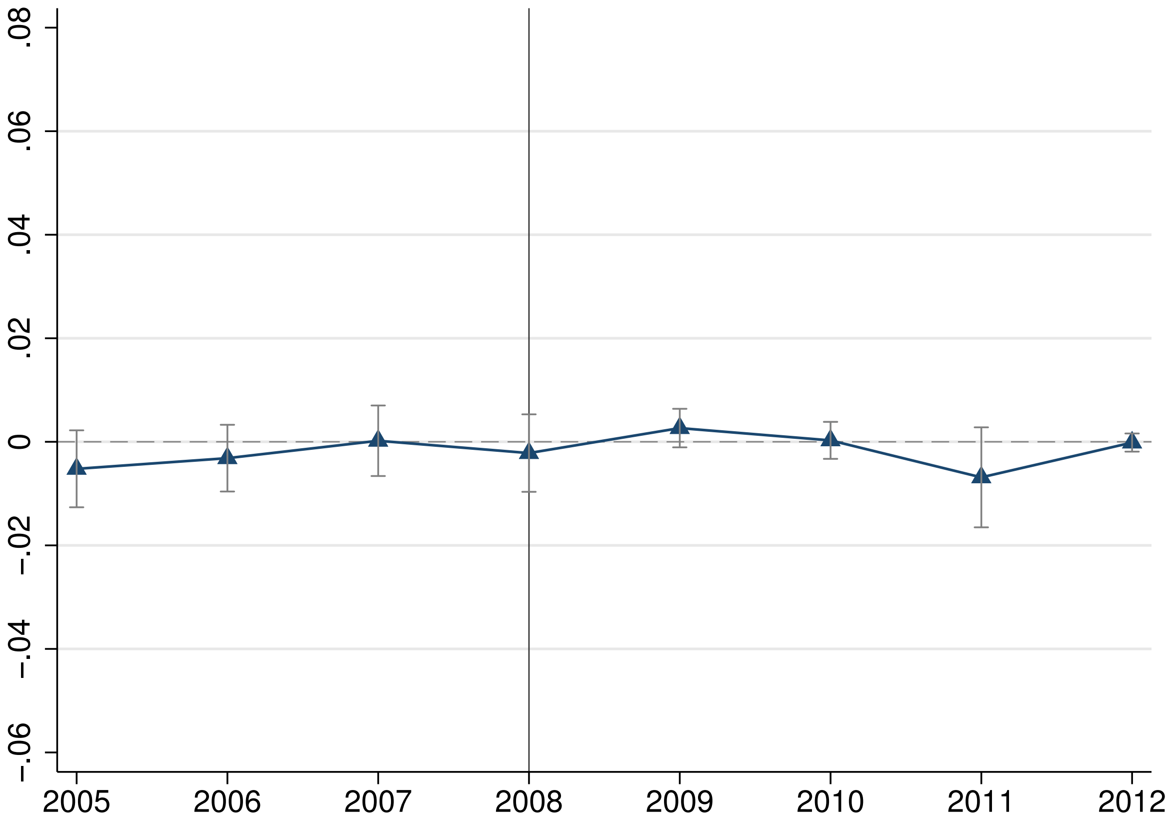
Notes: The figure demonstrates the method used to aggregate the gridded data on pollutant concentrations available from UBA to the district level using the district of Rostock as an example. The yellow shaded area represents the district area and the raster corresponds to the $57km^2$ grid cells containing pollution concentration averages as provided by UBA. The district level pollution concentration is computed by weighting each grid cell's pollution concentration impact according to the proportion of the district area it covers. The background map is provided by OpenStreetMap contributors.

Figure A6: Shares of Scrapped and Purchased Cars by Segment



Notes: The figure plots the shares of different car types (mini, small, compact, mid-range and others) of the cars scrapped and the cars purchased with the environmental premium. The data source underlying this figure is the final report of the federal office for economic affairs and export control (BAFA (2010)).

Figure A7: Traffic (Year-by-Year Changes)



Notes: The table reports estimates of event-study regressions of the effects of the environmental premium on traffic (4). The dependent variable is the log-change in the number of cars travelling on highways and federal roads between year $t-1$ and t (see Section 4.2) and hence the coefficients represent year-by-year effects. The regression controls for federal state x year fixed effects and market size controls and is weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *..

Table A1: Description of Control Variables

Variables	Description
Market Size Controls (measured in 2008)	
(Log-)Population	the total number of inhabitants in a district measured in logs
District Area	the area size of a district measured in km^2
Cars per Capita	passenger vehicles per 1000 inhabitants
Economic Characteristics (measured in 2008)	
Employment Share in Primary Sector (x100)	share of all employees subject to social security contributions in the agricultural sector
Employment Share in Secondary Sector (x100)	share of all employees subject to social security contributions in mining, manufacturing, energy and the construction sector
Unemployment Rate (x100)	unemployment benefits recipients as share of the sum of unemployment benefits recipients and all employees covered by the social security system
Disposable Income per Capita (in EUR)	disposable income of private households as measured in the national accounts
Productivity per Capita (in EUR)	gross value added per capita
Growth Variables (2005 to 2008 change)	
Population Growth	log population growth
Unemployment Rate Growth	absolute unemployment rate growth
Disposable Income per Capita Growth	log growth in disposable income per capita
Productivity per Capita Growth	log growth in gross value added per capita
Weather Controls (pre/post-policy change in pooled specification, yearly change in event-study)	
Change in Precipitation	measured in mm annual rainfall per m^2
Change in Average Daily Mean Temperature	measured in $^\circ C$

Notes: All variables are measured at the district level.

Table A2: The Effects on Car Purchases - Robustness

	Clunkers normalized by 2005 Purchases				Clunkers normalized by Population
	(1)	(2)	(3)	(4)	(5)
Clunkers x 2006	0.003***	0.004***	0.004***	0.004***	0.324***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.118)
Clunkers x 2007	-0.002	-0.001	-0.001	-0.001	0.099
	(0.002)	(0.002)	(0.002)	(0.002)	(0.153)
Clunkers x 2008	-0.001	0	0	0	0.318*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.192)
Clunkers x 2009	0.050***	0.051***	0.051***	0.051***	3.274***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.359)
Clunkers x 2010	0.003*	0.004**	0.004**	0.004**	0.570**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.263)
Clunkers x 2011	0.003	0.004**	0.004*	0.004*	0.507
	(0.002)	(0.002)	(0.002)	(0.002)	(0.317)
Clunkers x 2012	0.002	0.004**	0.003*	0.003*	0.593
	(0.002)	(0.002)	(0.002)	(0.002)	(0.367)
Federal State x Year FE	x	x	x	x	x
Market Size Controls (2008)	x	x	x	x	x
Economic Characteristics (2008)		x	x	x	x
Growth Variables (2005 to 2008)			x	x	x
Weather Controls				x	x
R2	0.98	0.98	0.98	0.98	0.96
N	3200	3200	3200	3200	3200

Notes: The table reports estimates of event-study regressions of the effects of the environmental premium on new car purchases based on variants of equation (2). We present cumulative effects by adding up the estimated effects of year-by-year regressions with the normalized change in car purchases between year $t-1$ and t as dependent variable over time. In columns (1) to (4) the measure of clunkers in a district is defined as clunkers per 2005 car purchases as described in Section (4.1). In column (5), instead, the clunkers measure is normalized by 2008 district population. Column (1) presents the baseline estimates equivalent to the estimates shown in Figure 7, sub-figure (b), controlling only for federal state x year fixed effects andmarket size controls. Column (2) additionally controls for local economic characteristics. The control variables in these specifications are measured pre-policy in 2008. Column (3) additionally controls for the 2005 to 2008 growth in local economic and demographic characteristics and column (4) and (5) for yearly changes in weather conditions. The control variables are described in more detail in Appendix A1. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table A3: The Effects on Emissions - Year-by-Year Effects

	NO2			PM10		
	District FE	Trend Ctrl	w/o Trend Ctrl	District FE	Trend Ctrl	w/o Trend Ctrl
	(1)	(2)	(3)	(4)	(5)	(6)
Clunkers x 2005	-0.036	-0.036	-0.024	-0.032	-0.032	-0.006
	(0.024)	(0.024)	(0.020)	(0.022)	(0.022)	(0.015)
Clunkers x 2006	-0.002	-0.001	0.011	-0.094***	-0.094***	-0.068***
	(0.026)	(0.026)	(0.020)	(0.020)	(0.020)	(0.016)
Clunkers x 2007	0.012	0.011	0.023	0.015	0.015	0.041*
	(0.032)	(0.032)	(0.020)	(0.027)	(0.027)	(0.022)
Clunkers x 2008			0.012			0.026*
			(0.017)			(0.014)
Clunkers x 2009	-0.043*	-0.044*	-0.032**	-0.052*	-0.051*	-0.025
	(0.026)	(0.026)	(0.013)	(0.027)	(0.027)	(0.017)
Clunkers x 2010	-0.072**	-0.073**	-0.060***	-0.055***	-0.055***	-0.029*
	(0.028)	(0.028)	(0.017)	(0.019)	(0.019)	(0.016)
Clunkers x 2011	0.007	0.007	0.019	-0.003	-0.002	0.023*
	(0.021)	(0.021)	(0.016)	(0.020)	(0.020)	(0.014)
Clunkers x 2012	0.025	0.024	0.037**	-0.03	-0.03	-0.004
	(0.020)	(0.020)	(0.016)	(0.024)	(0.024)	(0.018)
Clunkers		0.012			0.026*	
		(0.017)			(0.014)	
Federal State x Year FE	x	x	x	x	x	x
District FE	x			x		
Market Size Controls (2008)		x	x		x	x
Economic Characteristics (2008)		x	x		x	x
Growth Variables (2005 to 2008)		x	x		x	x
Weather Controls	x	x	x	x	x	x
R2	0.616	0.6	0.6	0.803	0.797	0.797
N	3200	3200	3200	3200	3200	3200

Notes: The table reports estimates of event-study regressions of the effects of the environmental premium on emission concentrations based on variants of equation (4). The dependent variable is the change in the respective outcome variable (NO_2 or PM_{10}emissions) between year $t-1$ and t (see Section 4.2) and hence the coefficients represent year-by-year effects. The set of control variables is described in more detail in Appendix Table A1. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table A4: The Effects on Emissions - Robustness II

	NO2				PM10			
	District FE	add Bartik Control	add Urban x Year FE	add LEZ Dummy	District FE	add Bartik Control	add Urban x Year FE	add LEZ Dummy
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Clunkers x 2005	-0.036	-0.037	-0.026	-0.045*	-0.032	-0.032	-0.032	-0.033
	(0.024)	(0.024)	(0.025)	(0.025)	(0.022)	(0.022)	(0.023)	(0.021)
Clunkers x 2006	-0.002	-0.001	-0.014	-0.01	-0.094***	-0.094***	-0.076***	-0.094***
	(0.026)	(0.026)	(0.028)	(0.026)	(0.020)	(0.020)	(0.021)	(0.020)
Clunkers x 2007	0.012	0.012	-0.015	0.003	0.015	0.016	0.004	0.014
	(0.032)	(0.032)	(0.035)	(0.031)	(0.027)	(0.027)	(0.028)	(0.027)
Clunkers x 2008								
Clunkers x 2009	-0.043*	-0.045*	-0.050*	-0.052**	-0.052*	-0.052*	-0.033	-0.056**
	(0.026)	(0.025)	(0.027)	(0.025)	(0.027)	(0.027)	(0.030)	(0.027)
Clunkers x 2010	-0.072**	-0.073***	-0.095***	-0.094***	-0.055***	-0.055***	-0.048**	-0.054***
	(0.028)	(0.028)	(0.030)	(0.029)	(0.019)	(0.019)	(0.020)	(0.019)
Clunkers x 2011	0.007	0.006	-0.007	-0.002	-0.003	-0.002	0.012	-0.002
	(0.021)	(0.021)	(0.021)	(0.023)	(0.020)	(0.020)	(0.021)	(0.020)
Clunkers x 2012	0.025	0.024	0.017	0.02	-0.03	-0.03	-0.028	-0.039
	(0.020)	(0.020)	(0.022)	(0.021)	(0.024)	(0.024)	(0.026)	(0.026)
Federal State x Year FE	x	x	x	x	x	x	x	x
District FE	x	x	x	x	x	x	x	x
Weather Controls	x	x	x	x	x	x	x	x
Bartik Control		x				x		
Urban x Year FE			x				x	
LEZ dummy				x				x
R2	0.616	0.617	0.621	0.625	0.803	0.804	0.805	0.804
N	3200	3200	3200	3200	3200	3200	3200	3200

Notes: The table reports estimates of event-study regressions of the effects of the environmental premium on emission concentrations based on variants of equation (4). The dependent variable is the change in the respective outcome variable (NO_2 or PM_{10} emissions) between year $t-1$ and t (see Section 4.2) and hence the coefficients represent year-by-year effects. Regressions are weighted by district population in 2008. Standard errors are clustered at the district level. Significance levels: 1% ***, 5% **, 10% *.

Table A5: Input data for back-of-the-envelope calculations

Euro class	NOx in gram/km				clunkers	new cars
	type-approval		real-world			
	petrol	diesel	petrol	diesel		
older	2.90	1.13	2.90	1.13	15%	0%
Euro 1	1.13	1.13	2.26	2.26	40%	0%
Euro 2	0.50	0.70	1.00	1.40	44%	0%
Euro 3	0.15	0.50	0.28	1.11	1%	0%
Euro 4	0.08	0.25	0.13	0.98	0%	79%
Euro 5	0.06	0.18	0.09	1.04	0%	21%

Notes: Type-approval and real-world emissions are taken from ICCT (2017). Pre-Euro 1 emissions are based on Nistad et al. (2020). Pre-Euro 1, Euro 1 and Euro 2 values are only available for the combined emissions of NO_x and HC. Unfortunately, we do not have data on real-world emissions for emission standards Euro 2 and lower. We thus conservatively assume that real-word emissions for Euro 1 and Euro 2 cars are two times as high as the type-approval emissions, and pre-Euro 1 emissions are equal to type-approval emissions. The share of clunkers by Euro class are based on IFEU (2009) and the share of subsidized cars by Euro class are based on BAFA (2010). We assume a constant diesel share of 7.5 percent in the fleet of scrapped and subsidized vehicles based on IFEU 2009. NO_x emissions from passenger vehicles in 2008 amount to 316.4 kt (based on the database "Zentrales System Emissionen" provided by the UBA).