# Rust in Motion: Impacts of Brazil's Anti-Scrappage Policy Through Vehicle Ownership Tax*

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March 2025

**Abstract**

Transportation is one of the main sources of GHG and pollution emissions worldwide, and recent studies have shown that the majority of automobile pollution comes from vehicles older than 10 years. Notwithstanding, existing policies create incentives against removing older vehicles from the fleet with potential pollution and public health impacts. This paper examines the impacts of an anti-scrappage policy in Brazil using a border-pair approach that leverages state variation in exemption ages for the vehicle ownership tax. Using municipality-level vehicle registration data from 2013-2020, we find that low-age exemption cutoffs can increase fleet age up to 1 year. Using fleet-based estimates and satellite-level data on global and local pollutants, we find that low exemption age policies are associated with up to 23% higher on-road CO2 emissions per capita and 4% higher concentrations of $PM_{2.5}$. Meanwhile, the rate of low birth weight measured from administrative birth records increases by 9.6% under a 10-year exemption policy and 2.5% in localities with exemption cutoff between 15 and 20 years. Despite the underscored social costs of these policies, we find suggestive evidence that electoral incentives make low-age exemptions politically costly to be overturned.

***JEL Codes:*** H23, I18, Q53, Q56

***Keywords:*** Vehicle ownership tax, vehicle-age-based tax exemption, transportation-driven local air pollution, infant health, birth outcomes, border-pair approach

*We thank Andre Cardoso, Ron Chan, Karen Clay, Akshaya Jha, and Xiaochen Sun for insightful suggestions, and seminar participants at Carnegie Mellon University for valuable comments. The authors gratefully acknowledge financial support from the Heinz College at Carnegie Mellon University and from Nova School of Business and Economics (Nova SBE). Monteiro's email address: gmonteir@andrew.cmu.edu. Severnini's email address: edson.severnini@bc.edu.

# 1 Introduction

The transportation sector stands as one of the leading contributors to global emissions.[1] While the optimal approach to tackle these externalities is through a Pigouvian tax on vehicle usage, many governments, particularly in developing countries, resort to imposing exhaust standards for new vehicles or heavy taxes on vehicle purchase or ownership due to enforcement simplicity, political acceptability, or equity concerns (He and Kim, 2024). Although most of the emissions from vehicle transportation are generated by older vehicles (Jacobsen et al., 2022), anti-scrappage policies worldwide offer incentives that encourage the continued operation of those vehicles, often with the aim of potentially benefiting low-income individuals.[2] Policies like annual tax or registration fees that decrease with vehicle age may extend the lifespan of older vehicles by reducing their relative cost compared to newer vehicles, therefore reducing scrappage rates. Because these policies can increase not only greenhouse gas emissions but also local pollution, they can have detrimental effects on public health.

In this paper, we exploit variation in exemption thresholds for vehicle ownership tax across Brazilian states to examine the effects of these thresholds on the age distribution of the vehicle fleet, local air pollution, and infant health. Brazil's vehicle ownership tax system serves as an emblematic example of how taxation policies can influence the lifespan of older vehicles. Under this system, vehicle owners annually pay a percentage of their vehicle's market value as a state tax, with exemptions granted in 25 out of 27 states once vehicles reach a predetermined age threshold. Given that older vehicles tend to be more polluting, the taxation structure imposes relatively lower costs on these vehicles, particularly after surpassing the exemption age cutoff. This stands in stark contrast to the principles of an optimal pollution mitigation policy, such as a Pigouvian tax system, which would entail higher costs per mile traveled for more polluting vehicles, thereby aligning with the external costs of emissions.[3]

We adopt a border-pair approach to identify the causal impacts of state policies, building on prior work by Holmes (1998) and Kahn and Mansur (2013). Distinguishing the effects of state

[1] The United Nations reports that the transportation sector accounts for about a quarter of global greenhouse gas emissions. In 45% of countries, transportation represents the largest source of energy-related emissions, while in other countries, it ranks as the second largest source.

[2] For the United States, Beck and Bennett (2003) documented that, in 1997, registration fees in 6 states declined with car age, and in 15 states registration fees declined with car value, which correlates with vehicle age. Thailand and Philippines also have policies that tax older vehicles at a lower level (Hirota and Poot, 2003).

[3] Nevertheless, taxing vehicle air pollution emissions is not feasible because direct measurement of individual vehicles is imperfect and prohibitively expensive (Venigalla, 2012).

policies from those of unrelated state characteristics poses a challenge, but the border-pair approach offers a means to address this identification issue. We organize municipalities near state borders into paired groups using a simple algorithm, forming state-layer pairs. Our approach relies on the assumption that, in the absence of policy differences, municipalities on opposite sides of the state border should exhibit similar characteristics and outcomes. To mitigate potential threats to identification, we incorporate a range of geographical and local characteristics into our econometric specifications as well. Ultimately, we leverage variations in exemption ages for the vehicle ownership tax within state-layer pairs, comparing municipalities facing low state exemption ages to municipalities in our baseline group of states with *de facto* no exemption policies. In our primary analysis, we focus on municipalities within the first two layers of pairing, but we conduct sensitivity analyses using different layer compositions to ensure the robustness of our findings.

Our analysis reveals that exempting vehicles aged between 10 and 20 years leads to a fleet with a higher average age compared to scenarios where there is no exemption policy in place. We categorize exemption policies into three groups based on vehicle age thresholds: states with a cutoff age of 10 years, states with a cutoff between 15 and 20 years, and states with either no exemption or exemption only for vehicles aged at least 28 years. We designate the latter group as our benchmark, considering them to effectively have a no-exemption policy due to the minimal presence of vehicles in the fleet exceeding 28 years of age. Using vehicle registries at the municipality level of the Brazilian Ministry of Transportation, we find that states with lower exemption ages exhibit an average vehicle age approximately 0.5 to 1 years older than states in our baseline group. Additionally, we find evidence indicating a higher share of vehicles surpassing the exemption threshold on the side of the border under the policy. Given its observed effects on the fleet age, a low exemption-age threshold from the vehicle ownership tax is an example of anti-scrappage policy.

Our findings also indicate that states implementing relatively low age exemption policies experience higher greenhouse gases emissions, elevated local pollution levels, and poorer birth outcomes, which can be attributed to the age distribution of the vehicle fleet. Based on SEEG municipality-level emissions estimates, we find that municipalities subject to a 10-year exemption cutoff exhibit, on average, on-road $CO2$ emissions per capita approximately 23% higher than the baseline, representing an additional 23 ton per capita, the equivalent of the emissions of an extra gasoline-powered passenger vehicle for each 20 residents. [4] Leveraging satellite-derived data on pollutants from MERRA-2, we observe on average in

[4]Conversion from $CO2$ emissions into passenger vehicle annual emissions were made using EPA's Greenhouse Gas Equivalencies Calculator. The equivalency is based on an estimate of 4.29 tons of $CO2e$ emissions/year by the average gasoline-powered passenger vehicle.

low age exemption municipalities, a concentration of fine particulate matter 2.5 ($PM_{2.5}$) around 4% higher, and a concentration of carbon monoxide around 7% and 8% higher than the baseline. Furthermore, using administrative data from the Brazilian Ministry of Health, we discover that these policies are associated with lower average 5-minute Apgar score (from a 0.07 decrease for the 15-20 exemption group to a 0.18 reduction in the 10-year exemption), higher rates of low birth weight (ranging from additional 2.0 to 7.8 per thousand live births in the 15-20 and 10-year cutoff groups respectively), and higher rates of 28-day infant mortality (0.65 higher per thousand live births) for the lowest exemption age states.

Our results suggest that, contrary to the argument that low exemption ages facilitate vehicle ownership for lower income families, equity benefits to the policy are not sizable. Explicitly, we do not find significant impacts of relatively low exemption age on the number of vehicles per capita, and poorer municipalities under a 15-20-year threshold have most impacts of the policy muted. Besides environmental and health negative impacts, overturning exemption is politically costly. We find suggestive evidence that incumbent politicians associated with weakening anti-scrappage exemptions are punished electorally. Using the case of Mato Grosso do Sul (MS), where the governor increased the exemption age from 15 to 20 years and later ran for reelection, we compare the candidate's vote share across municipalities with varying vehicle age compositions in the cycles before and after the policy change. We find that, for each additional percentage of vehicles under the exemption age, the incumbent governor lost 1.12 percentage points of votes compared to his previous election.

This paper makes three main contributions to the literature. First, it contributes to the emerging literature on the ways in which non-environmental policies can impact environmental outcomes. Previous research has shown that policies seemingly unrelated to the environment can have significant environmental effects, such as the environmental bias observed in trade policy (Shapiro, 2021). The vehicle ownership tax policy in Brazil, particularly its exemption for older cars, offers a unique lens for understanding the interplay between non-environmental policies and their environmental ramifications. We contribute to this literature by shedding light on how tax incentives for older vehicles can inadvertently hinder efforts toward scrappage schemes, leading to increased GHG emissions, local pollution, and public health concerns. Our contribution underscores the importance of considering the indirect environmental implications of apparently unrelated fiscal policies, urging policymakers to adopt measures that align with broader sustainability goals.

Second, it contributes to the literature on the design and implementation of policies to reduce the environmental footprint of transportation. Prior research has shown that vehicle taxes can be consequential to fleet age distribution and emissions efficiency (Klier and Linn,

2015; Yan and Eskeland, 2018; Gillingham et al., 2022), but other policies such as driving restrictions might be ineffective and even change the fleet composition toward high-emissions vehicles (Davis, 2008).[5] While most of the literature studies these issues in developed country settings, it is unclear whether the findings are applicable to poorer countries because of corruption and limited state capacity (Oliva, 2015). We contribute to this literature by providing a *nationwide* evaluation of the effects of vehicle age exemption policies in a developing country context, highlighting the broad unintended consequences against sustainability to the fleet composition.

Third, it contributes to the literature on the impact of transportation emissions on infant health.[6] Advancements in the recent literature have shown that transportation related increases in pollution levels cause higher rates of low birth weight and of infant mortality (Currie and Walker, 2011; Knittel et al., 2016; Alexander and Schwandt, 2022; Hansen-Lewis and Marcus, 2022). While most of the existing evidence corresponds to developed countries, there is a concern that magnitudes might differ in developing countries due to factors like lower willingness to pay for avoidance behavior, higher usual pollution levels, and limited healthcare infrastructure (Greenstone and Hanna, 2014; Arceo et al., 2016; Guidetti et al., 2021). We contribute to this literature by analyzing the effects of an older, more polluting fleet on birth outcomes in a developing world setting, emphasizing the nontrivial impacts on infant health.

This paper is structured as follows. In Section 2, we describe and contextualize Brazil's vehicle ownership tax, emissions standards, and how they can impact the fleet. In Section 3, we describe our data and the algorithm to build the border-pairs. We introduce our border-pair empirical strategy in Section 4. Main results are presented in Section 5. We discuss and provide suggestive evidences on the political economy consequences of weakening this anti-scrappage policy in Section 6. Section 7 concludes.

# 2 Institutional Background

## 2.1 Vehicle Ownership Tax (IPVA)

The Vehicle Ownership Tax is a state tax paid annually by owners of motor vehicles, e.g. cars, motorcycles, trucks. The tax was added to the Brazilian Constitution in 1985, first taking

[5] 'Cash-for-Clunkers' programs have also presented impacts on the composition of the fleet with positive effects on CO2 emissions and air quality (Li et al., 2012; Helm et al., 2023).

[6] Many papers also study the effects of pollution more broadly on birth outcomes and infant mortality (Chay and Greenstone, 2003; Currie and Neidell, 2005; Currie et al., 2015). Studies of air pollution on other health outcomes include Neidell (2004), Neidell (2009), and Moretti and Neidell (2011).

effect in the following year and establishing that 50% of the tax revenue being destined to the state and 50% to the municipality where it is registered. The vehicle should be registered at the owner's municipality of residence.

Although the object of taxation and the rules for division of tax revenue were loosely defined at the federal level, most of the tax features are defined at the state level. Each state sets a tax rate that can vary according to fuel and vehicle type, and the value of the tax is obtained by applying the tax rate to the vehicle's market value. Also, each state can set their own rules for exemption from the tax.

The main purpose of the Vehicle Ownership Tax is being a source of revenue for the states. States in Brazil rely on three taxes: i) Goods and Services Value-added Tax (*ICMS*), ii) Vehicle Ownership Tax (*IPVA*), and iii) Donation and Inheritance Transfer Tax (*ITCD*). The Vehicle Ownership Tax represented, in 2020, 8.25% of the total revenue of state taxes nationally, behind only the wide and complex Goods and Services Value-added Tax which comprised 90% of total revenue.

However, some features of the Vehicle Ownership Tax have clearly objectives other than maximizing revenue. For example, some states set lower tax rates for electric vehicles or vehicles that run on ethanol or natural gas compared to gasoline. This serves as an incentive for adopting vehicles that emit less greenhouse gases. In Sao Paulo – the most populous state in the country –, vehicles running on gasoline or diesel have a 4% tax rate, while electric vehicles and vehicles running on natural gas or ethanol have a 3% tax rate. More dramatically, in Rio de Janeiro – the third most populous state –, gasoline or diesel vehicles face a 4% tax rate, while natural gas vehicles have a 1.5% tax rate, and electric vehicles have a 0.5% tax rate.

Another common feature of the tax is an exemption age threshold. In 2013, all but two states (Minas Gerais and Mato Grosso) had an age threshold after which the vehicle would be exempt from the ownership tax. In Figure 1, panel (a), we see that the majority of the states set an age threshold between 15 and 20 years after which the vehicle is exempt. In 2013, four states exempted vehicles older than 10 years, four states had an exemption age threshold higher than 28 years (including states with no age exemption), with the remaining 19 states having a threshold between 15 and 20 years.

During our period of analysis, six states conducted some type of change in their rules for exemption by vehicle age. In 2015, Alagoas (AL) changed their 15-year threshold into an exemption for vehicles manufactured in 2000 or earlier, Tocantins (TO) eliminated their 15-year exemption age benefit, and Mato Grosso do Sul (MS) raised the exemption age threshold

from 15 years to 20 years. In 2018, Santa Catarina (SC) changed their law that exempted vehicles manufactured in 1985 or earlier into an exemption for vehicles older than 30 years, and Mato Grosso (MT) adopted a vehicle age threshold of 18 years for tax exemption in place of the previous policy without exemption by age. Interestingly, Goias (GO) increased the age threshold from 10 to 15 in 2015 only to decrease the exemption age back to 10 years in 2018. All changes to the Vehicle Ownership Tax are effective in the following year.

The monetary cost of the vehicle ownership tax is non-negligible, even for owners of older and less expensive vehicles. In 2013, considering an individual receiving the average income and owning a popular ten year old vehicle, a tax rate of 3% would represent around 2% of the individual's annual income.[7] [8] If the same individual instead owned a 15-year-old model of a popular car, the tax rate would represent around 1.3% of the annual income.

In Figure 1, panel (b), we present an example of the vehicle age distribution in two neighboring states, Rio de Janeiro (RJ) and Minas Gerais (MG). MG is a state without any exemption age cutoff, while RJ is a state with a 15-year threshold after which vehicles are exempt from taxation. We can see that the two states follow a similar pattern until the age of 10 years, although MG has a higher density of vehicles for that age bracket. However, from 10 to 15, we see a gap opening with RJ having a growing higher density of vehicles, as owners do not scrap vehicles in anticipation to the future lower costs of vehicle ownership. From 15 to 20, the gap starts fading, suggesting that owners that postponed the scrappage decision realize it after some periods of lower ownership cost.

## 2.2 Emissions: Standards and Deterioration

A consequence of prolonging the lifetime of vehicles is an increase in the levels of fleet pollution. This is generally a result of two phenomena: technological advancements driven by regulation reduce the emissions of new vehicles through the years; and, holding vehicle-model constant, vehicles' emission rates increase with age due to deterioration of emission control systems.[9]

[7] We obtain the monthly average usual income from Brazil's Continuous National Household Sample Survey (*PNAD Continua*) using the IPEADATA repository. The average monthly income in December 2013 was 1,628 BRL, which is annualized to 19,536 BRL.

[8] We obtain data of vehicles' market value using the *Tabela FIPE*, which is used by the state governments to calculate tax value. Because the most selling vehicle model in 2003 and 1998 (10 and 15 years before 2013) was Volkswagen's Gol, we pick the vehicle *Volkswagen Gol 1000 Mi 4p* as our reference. In December 2013, the market value of a 10-year-old vehicle of the model was 12,643 BRL, and the market value of a 15-year-old vehicle of the same model was 8,668 BRL.

[9] Jacobsen et al. (2022) demonstrates these phenomena in the context of the US fleet and regulation environment.

Brazil's regulatory efforts to limit motor vehicles pollution emissions start with the creation of the Control Program for Motor Vehicle Air Pollution (*PROCONVE*) in 1986.[10] It is then laid out a schedule of successive phases gradually reducing the limits for emission rates of different types of vehicles, focusing initially on carbon monoxide (CO), total hydrocarbons (HC), and nitrogen oxides (NOx). Appendix Table A.1 presents the past PROCONVE phases for gasoline-powered light-duty (L-Standards) and diesel-powered heavy-duty (P-standards) vehicles. The reductions in emissions standards are striking: taking gasoline-powered light-duty vehicles (LDV) as an example, CO emission limits decreased from $24g/km$ in phase L1 (1989-1991) to $1.3g/km$ in phase L6 (2014-2021) at the end of our analysis, a reduction of about 95%.

Progressively stricter emission standards led to conforming declines in the emission rates of new vehicles. Using calculations from CETESB (Sao Paulo State Environmental Agency) for average emission rates of new gas-powered LDVs from 1985 to 2020, we plot in the Appendix Figure A.1 the reductions in CO and NOx emission rate – regulated by PROCONVE – and CO2 starting in 2002.[11] Average emission rates of both CO and NOx for new vehicles in the category fell by about 99% in the period. From 2002 to 2020, average CO2 emissions – which are not limited by PROCONVE standards – decreased by approximately 25%.[12]

Moreover, vehicles' emission control systems deteriorated with age and usage, such that, even holding vehicle characteristics constant, the older used vehicle is more polluting. In Appendix Figure A.2 we show estimates from CETESB for average "deteriorated" emission rates by fleet-vintage from 2013 and 2020. While the 2013 gas-powered "flex-fuel" fleet would emit, on average, $0.25g/km$ of CO and $0.03g/km$ of NOx when new, after 7 years, in 2020, the average emissions for the same fleet more than doubles with $0.57g/km$ of CO and $0.07g/km$ of NOx.

With progressively lower emission rates from new vehicles, if pollution emissions from manufacturing new vehicles are not too large, it becomes welfare-increasing to accelerate the renewal of the fleet using vehicle fees (Jacobsen et al., 2022). However, the design of Brazil's Vehicle Ownership Tax acts in the opposite direction: fees decrease in vehicle age – and falling to zero after exemption age – at the same time as environmental externality costs of

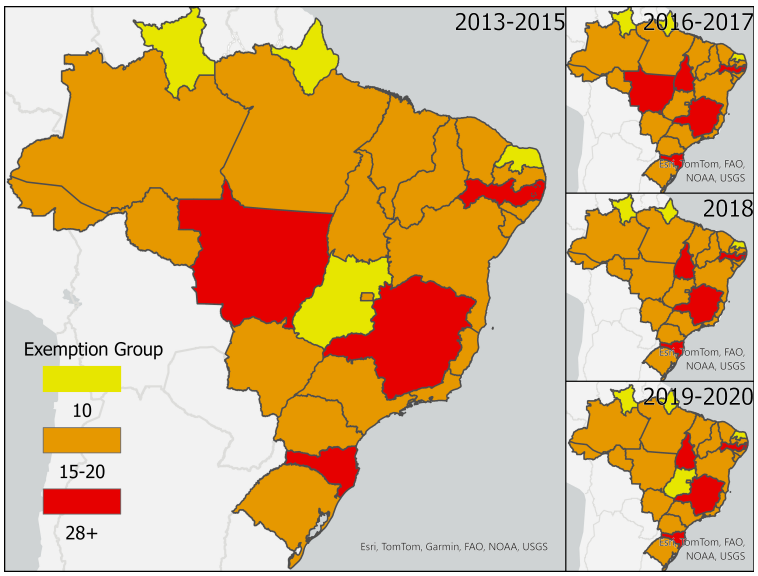
[10] The program is created via the *CONAMA* (National Environmental Council) Resolution 18 of May $6^{th}$, 1986: https://conama.mma.gov.br/?option=com_sisconama&task=arquivo.download&id=41 .

[11] CETESB's emission reports and emission factors data are available in: https://cetesb.sp.gov.br/veicular/relatorios-e-publicacoes/.

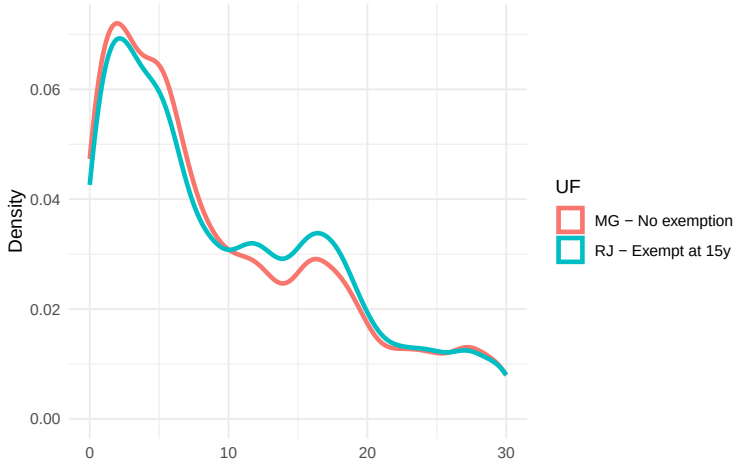
[12] CO2 emissions are typically targeted with fuel economy standards. In 2009, Brazil introduced a (primarily) voluntary Vehicle Labeling Program (PBEV) to promote energy efficiency. Participation in the labeling program becomes mandatory with the *Rota 2030* Program (Law 13,755 of December $10^{th}$, 2018.) that also targeted a 11% reduction in the fuel consumption of the fleet of new vehicles by 2022.

vehicle use increase. This policy that relatively reduces costs of ownership of older vehicles compared to new ones, thus, creates an incentive to keep older heavier-polluting vehicles in the fleet, increasing the fleet's average emissions of global and local pollutants.

Figure 1: States Exemption Age Thresholds and Fleet Age Density




(a) Maps of Exemption Age Threshold




(b) Two-State Example: Density of Fleet Age

*Notes:* In Panel (b), density is calculated with gaussian kernel with a 1-year bandwidth. Sample was limited to vehicles with at maximum 30 years.

# 3 Data

## 3.1 Layers and Borders

Our analysis is done at the municipality level, the administrative divisions within Brazilian states. Using a 2007 map of the 5,563 Brazilian municipalities we obtain their borders and geographical centroids.[13]

In our main analysis, we rely on border-pairs, which are groups of geographically-matched municipalities close to state borders. To create these border pairs, we have a three-step process: i) assigning municipalities to border layer levels, ii) match municipalities to their closest out-of-state neighbor with same layer level, and iii) group municipalities with same layer level and matched to same neighboring state.

The designation of a municipality to a layer level has a very simple recursive algorithm. In Figure 2, panel (a), we can observe an example of layer groups across neighboring states. Municipalities on the border of their state are assigned as being in the first layer. The second layer is composed of municipalities that are not on the border of their state but are bordering a municipality in the first layer. [14] The remaining municipalities are not included in our border-pair analysis.

In the second step, we match municipalities to their closest out-of-state neighbor of same layer level. For that we trace the linear bilateral distances between the centroids of every pair of municipalities in the country. Then, for every municipality on a given layer level, we find the municipality in another state and on the same layer level with the minimal linear distance. This creates a municipality pair.

In the third and last step, we group municipalities according to their pairings. We group together municipalities in a given state-layer that were paired to the same neighboring state. This creates a state-border layer. This process creates a total of 249 state-border layers, which can be aggregated into 98 state-borders.

We present a summary of statistics of relevant variables, in Appendix Table B.2, for municipalities in Layers 1 and 2 (main sample), as well as for all municipalities, and municipalities excluded from Layers 1 and 2. Municipalities in Layers 1-2 have their centroids, on average, 26 miles away from the closest state border, naturally closer than excluded municipalities

[13] Map of municipalities is made available through the Brazilian Institute of Geography and Statistics at: geoftp.ibge.gov.br/cartas_e_mapas/bases_cartograficas_continuas/bcim/versao2010/bcim_v3.04_dados/shapefile/.

[14] We also build a third layer, included only in robustness exercises, with municipalities being assigned to this layer if they not in the previous ones but are bordering a municipality in the second layer.

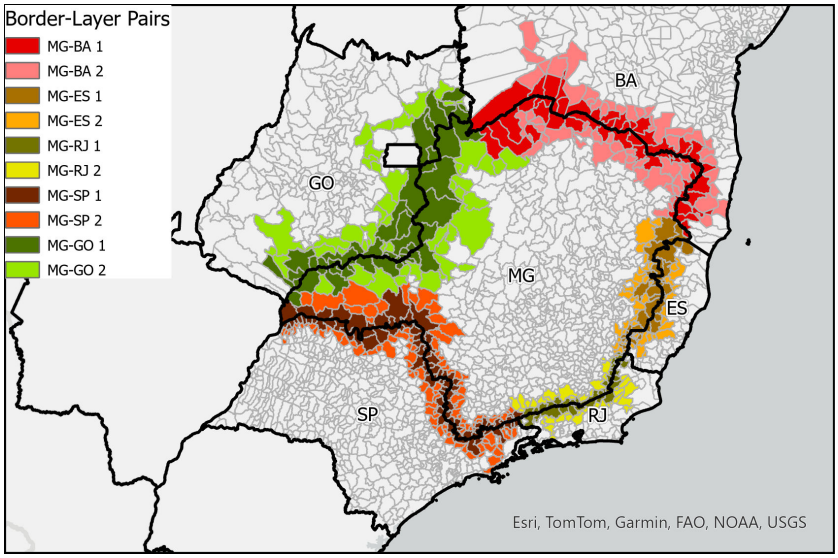
with an average distance of 83 miles. On average, municipalities in the main sample have smaller populations than excluded ones, however they present similar levels of GDP per capita. In general, municipalities in the main sample tend to have relatively newer fleets, lower emissions, and mostly better health outcomes.

## 3.2 Vehicle Data

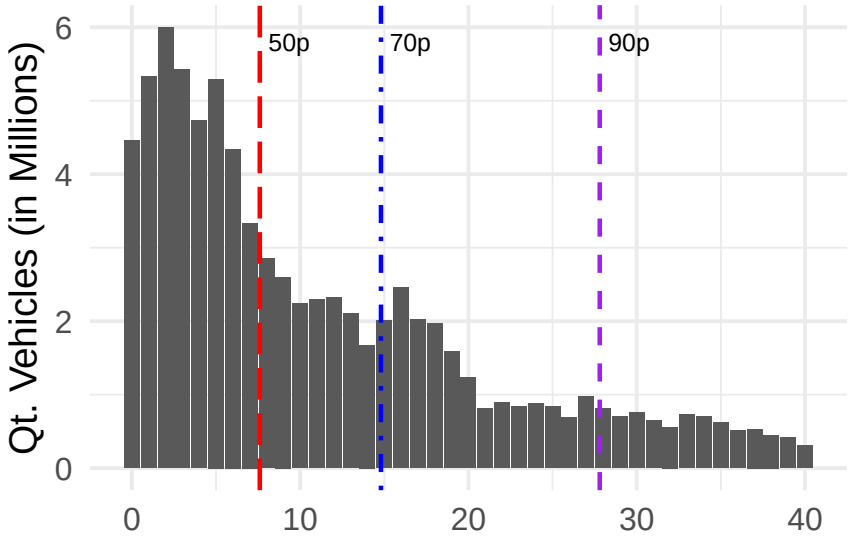
Our data on the vehicle fleet is a public-available aggregation of Brazil's National Registry of Motorized Vehicles (RENAVAM) published by the Ministry of Transportation. Every new vehicle sold in the country is registered in the RENAVAM system with an identification number though the local Department of Transit. This identification number is then used to track the vehicle's history at each change of ownership, update of residence at a local Department of Transit, or when a vehicle is formally updated as scrapped.

In our aggregated data, we obtain for the information of the number of registered vehicles at each municipality by year of manufacturing for each year from 2013 to 2020. With that we are able to construct a measure of the distribution of vehicle age at the municipality level. In Figure 2, panel (b), we observe this distribution of vehicles by age, the figure presents an aggregation at the country level in 2013, for vehicles with age up to 30 years. We observe that the majority of vehicles was under 10 years, with a median age of 7.6 years. However, a sizable amount of the vehicle stock was aged between 10 and 20 years, on the region where states usually set their exemption age thresholds. Also, according to our data, less than 10% of the fleet had an age over 28 years, implying a very small share of vehicles was impacted in the states using a threshold at that level or higher.

Figure 2: National Fleet by Age and Layer Levels




(a) Example of Layer Levels in MG-'Neighbor' Borders




(b) Vehicles by Age, 2013

*Notes:* In Panel (a), darker colors represent low layer levels. Border pairs are organized according to color groups. In Panel (b), bars represent the total amount of vehicles nationally (in millions) in 2013 for each given age. The red long-dashed line indicates the median age of vehicles, 7.6 years. The blue dotted-and-dashed line indicate the 70th age percentile of the fleet, 14.8 years. The purple dashed line indicate the 90th age percentile of the fleet, 27.8 years.

A shortcoming of our dataset is that we do not observe the intensity of vehicle use. Emissions occur through vehicle circulation, but our data accounts equally for vehicles that are in active

use and vehicles that are out of use but not formally removed from the Department of Transit system. In fact, estimates for the circulating fleet (IBPT, 2019) are considerably smaller than the total registered fleet.[15] For example, in 2013, the circulating fleet was estimated at 59.6 million vehicles, approximately 27% smaller than the total registered fleet (81.6 million vehicles). Another potential issue is the informal scrapping of vehicles, without notification to the Department of Transit. If that occurs, the vehicle is not removed from the dataset, leading to an overestimation of total fleet. This would also inflate the population of older vehicles, as there is no systematic way of removing vehicles from the registry if the owner does not inform the Department of Transit.

However, because all states follow the same guideline for vehicles registry, these concerns should not present a threat to our estimates. Our methodology holds the assumption that municipalities close to the border will be very similar across neighboring states, except for differences in state policies. Unless municipalities close to the border on neighboring states have systematically different rates of non-notification of scrappage, differences on the distribution of vehicle age should be driven by differences in state policies.

## 3.3 Pollution Data

To measure on-road emissions, we use municipality-year estimates of pollution emissions by activity from *Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa* (SEEG) – an initiative from *Observatório do Clima* (De Azevedo et al., 2018). SEEG's methodology is based on the IPCC guidelines and on Brazil's National Inventory of GHG Emissions and Removals. [16] On-road emissions are calculated using a fleet-based bottom-up approach that considers the fleet's characteristics, usage, and emission efficiency. In our main analysis, we use their estimates for on-road CO2 and NOx municipality-year emissions.

We use satellite data for PM2.5 and carbon monoxide concentrations from MERRA-2 (Gelaro et al., 2017) – the latest version of global atmospheric reanalysis produced by NASA Global Modeling and Assimilation Office (GMAO). We aggregate the monthly gridded data (dimension $0.5^o \times 0.625^o$) of pollutants at the municipality year level using the average value of pixels (partially) within the municipality. In the case of fine particulate matter, we calculate the municipality averages of the five aerosols comprising the pollutant and use a formula to

[15] The estimates for circulating fleet exclude vehicles with over an year of debts on the vehicle ownership tax (IPVA) or on the mandatory governmental insurance for vehicle accidents (DPVAT), as well as non-recovered stolen vehicles and vehicles declared as total loss after accidents.

[16] Most recent methodological notes are available at: https://seeg.eco.br/en/seeg-methodology/.

construct average PM2.5 concentration level.[17] [18]

Using satellite-level data gives us the benefit of observing pollution levels equally across all regions of the country, which would not be possible with monitoring stations. Similarly to other developing countries, ground-based air pollution monitoring is very limited in Brazil, with 11 out of 27 states with no monitoring and overall small coverage in remaining states as recently as 2023.[19] A shortcoming of using satellite data on pollution is that they are not a direct measure of on-the-ground pollution, with a potential downward bias at higher pollutant concentrations Fowlie et al. (2019). For our analysis, this issue would implicate in an attenuation bias, potentially underestimating differences in pollution levels across states.

## 3.4 Health Data

We use administrative data from the Brazilian Unified Health System Database (DATASUS). We collect data of birth and death records including information on Apgar score, weight at birth, and age at the time of death. We construct indices for individuals born at low birth weight (less than 2,500 grams), very low birth weight (less than 1,500 grams), and death within a 28-day period after birth. We aggregate these variables at the municipality-year level to obtain average 5-minute Apgar score, and rates of low, very low birth weight and 28-day infant mortality per 1,000 live birth. Birth weight is commonly used as a summary measure of infant health, and low birth weight has been associated in the literature with poor outcomes on health-related and economic measures later in life (Black et al., 2007; Almond et al., 2018). We also collect, from DATASUS, information on total number of hospital beds in the municipality and location of health units, which are used as control variables in our main analysis.

## 3.5 Election Data

The election process and laws in Brazil are set and supervised at the federal level, even for low administrative levels such as the states. State elections in Brazil occur synchronously

[17] We follow the documentation from MERRA-2 to obtain the PM2.5 concentration from the column mass density of black carbon, dust, sea salt, organic carbon, and sulfate.

[18] We verified $PM_{2.5}$ measures from Van Donkelaar et al. (2021) but did not find it suitable to our context. Differently from MERRA-2, Van Donkelaar integrates satellite with ground-based measurements, but Brazil presents limited on-the-ground monitoring for air pollution, with important variation on monitoring intensity across states. Upon checking van Donkelaar measurements of $PM_{2.5}$ in our setting, it did not show significant correlation with the controls of most known polluting sources, unlike MERRA-2.

[19] Brazil's 2023 Annual Air Quality Monitoring Report is available at https://www.gov.br/mma/pt-br/assuntos/meio-ambiente-urbano-recursos-hidricos-qualidade-ambiental/qualidade-do-ar/relatorio-anual-2023/relatorio-anual-da-qualidade-do-ar-2023.pdf.

across states on a fixed 4-year schedule concomitantly with federal-level elections. Executive branch elections can be held in two rounds: if no candidate achieves a majority of valid votes cast on the general election day, a second round is triggered between the top two candidates with voting happening three weeks later. A candidate with the majority of votes in the first (or second) round wins the election. Office holders in the executive branch are limited to two consecutive terms, but are able to serve for more terms if not bounded by the consecutive limit.

We obtain electoral data from Brazil's Superior Electoral Court for the gubernatorial races of 2014 and 2018, the two that occurred during our period of analysis. The data contains municipality-level vote counts for each candidate. We use only data from the first round of elections for comparability, since the existence of a second round is conditional on no majority formed in the first one.

## 3.6 Additional Data

To capture confounding state policies that could impact our estimates, we obtain information on the basic Value-Added Tax rate in every state for the period of analysis. Also, since fuel commonly has specific tax rates, apart from the basic VAT rate, we obtain information on gasoline prices from *Agência Nacional do Petróleo* (ANP). We average annual inflation-adjusted gasoline prices at the state level, excluding the contribution of the own observed municipality.[20] Moreover, we obtain data on municipality population from the 2010 Population Census and municipality-year GDP per capita from IPEADATA.

Due to concerns of differing activities or policies impacting location of polluting activities we obtain information of placement of fossil fuel and biomass thermal power plants, fire areas, legal amazon location, and mining sites. All data is collected from MapBiomas, a collaborative network formed by NGOs, universities, and technology startups focusing on gathering and organizing information on land cover, land use and management of natural resources in the Brazilian territory (Souza et al., 2020). For fossil fuel and biomass thermal power plants we were able to obtain cross-section data of all facilities as of August 2022. For the information on fires, we obtain maps of the areas impacted by fires each year in Brazil. We use that to calculate the share of the municipality that has been impacted by a fire during each year. For the information on mining activity, we are able to obtain a panel

[20] Consider municipality $m$ in state $S$ at year $t$. We build a 'clean' state-year average for the municipality by calculating $g_{-m,S,t} = \frac{1}{N-1} \sum_{i \in S} g_{i,S,t}$, where $g_{i,S,t}$ is a municipality-year average of gasoline prices. An exception is made for the Federal District which is comprised of a single municipality, where we apply the single municipality average for the state.

for the area used for mining sites in each municipality for all our years of analysis.

Additionally, to control for potential higher traffic of vehicles in municipalities with presence of Interstate Highways, we obtain the maps for all Interstates in 2020 from the World Bank.[21] From that we obtain the municipalities cut by an Interstate.

# 4 Border-Pair Approach

## 4.1 Methodology

We want to compare the effects of different exemption age thresholds for the vehicle ownership tax, which is a policy set at the state level in Brazil. However, it is not simple to distinguish effects of state policies from the effects of state characteristics that are unrelated with these policies. To confront this issue, we implement a border-pair approach building on Holmes (1998).

If an experiment was possible, we would randomly apply different exemption age thresholds to municipalities such that, on average, the groups of municipalities would be equal in all characteristics except for the different policies applied. In the border-pair approach we try to approximate that by restricting our analysis to municipalities close to the state border, under the assumption that the assignment to the side of the border they are located is 'as good as random', such that these localities are similar in characteristics other than the policy.

However, a potential criticism to this assumption is that state borders are commonly designed following previous geographical or other types of differences between locations. Taking that in consideration we control for a comprehensible set of observable characteristics, under a weaker assumption that conditional on these observed characteristics the assignment to a side of the border is 'as good as random'.

Moreover, we also need to define how close to the border are we limiting our sample. We assume that municipalities close to the border should be similar in both observable and non-observable characteristics, but, as we become farther away from the border, differences are potentially increasing. This creates a bias-variance trade-off, where accepting a larger bandwidth potentially reduces the variance of our estimates while adding bias. In our main specification, we limit our sample to municipalities in the first and second layers of the border, as a form of balancing this trade-off. In our robustness check we also test specifications including only the first layer, including all layers, and defining bandwidth limits by distance

[21] Maps of Brazilian Interstate Highways are available in: https://datacatalog.worldbank.org/search/dataset/0038536.

to the border.

Our main econometric model is represented in Equation 1:

$$y_{mt} = \beta_1 1\{Exempt\ 10\}_{S,t} + \beta_2 1\{Exempt\ 15-20\}_{S,t} + T'_{S,t}\delta + X'_{mt}\theta + \mu_{s_m - s'_n,t} + \epsilon_{mt}. \quad (1)$$

The variables $1\{Exempt\ 10\}_{S,t}$ and $1\{Exempt\ 15-20\}_{S,t}$ are dummies equal to 1 if, at time $t$, the exemption age threshold in state $S$ is at 10 years or between 15 and 20 years, respectively. The category for municipalities with exemption age threshold above 28 years is omitted, such that the parameters $\beta_1$ and $\beta_2$ capture the comparison to this baseline category. The vector $T_{S,t}$ measures the tax rate of vehicle ownership, at each state and year, for different types of vehicles: gasoline cars, ethanol cars, trucks, and motorcycles. We use the vector of variables $X'_{mt}$ to symbolize our set of additional controls that can be categorized as geographic, economic and policy, environmental, and health controls. The border-pair is introduced by the set of fixed-effects $\mu_{s_m - s'_n,t}$, that captures the pairs of border-layers between neighboring states at each year. A municipality-year specific error term is represented by $\epsilon_{mt}$.

The set of geographic controls include: linear distance to the border (split between higher and lower exemption age side), region fixed effects, municipality area, and quadratic functions of the municipalities' latitude and longitude centroids, as well as of average temperature, atmospheric pressure, and accumulated precipitation. Economic and policy controls include: current and lagged log GDP per capita, population size, inflation-adjusted state-year average (excluding own municipality) gasoline prices, basic value-added tax rate, and presence of Interstate Highway. Environmental controls include: share of the municipality area impacted by fires, and presence of mining site, fossil fuel thermal power plant, and presence of biomass power plant. Health infrastructure controls include: presence of health facility in the municipality, and the total number of beds in health facilities.

## 4.2 Pairing Border-Layers

We pair groups of municipalities in border-layers as described in Section 3. The effect of exemption age is identified by the variation from border-pairs where each side belongs to a different exemption group. There are three exemption groups – Exemption at 10 years, Exemption cutoff between 15 to 20 years, and exemption cutoff at 28 years or above – , creating three possible combinations of pairs of different groups.[22] An example of our identifying sample in the year 2013 is in the Appendix Figure C.1.

[22]The combinations are border pairs with types: 10 / 15 − 20, 10 / 28+, and 15 − 20 / 28+.

By limiting our analysis to municipalities close to the border, we intend to minimize potential differences between the groups in absence of the policy difference of interest. In Appendix Table C.1 we analyze differences in characteristics of municipalities with exemption cutoff at 10 or from 15 to 20 years compared to municipalities with an exemption age above 28 years using the border-pair approach and including layers 1 and 2. We include controls for region fixed effects, as well as latitude and longitude quadratic polynomials, to capture geographical heterogeneities of the variables.[23] For a large variety of local characteristics there are no significant differences across state borders, including: VAT base rates, gasoline prices, total number of beds in health facilities, presence of interstate highways and fossil fuel power plants, log GDP per capita, population, area, and precipitation. However, we find differences in other characteristics including distance to the closest border, presence of mining activities and health care facilities, share of fire-impacted area, and average temperature between the no-exemption and low-exemption age groups. Our main specification includes controls for all these observable local characteristics.

# 5 Main Results

In Table 1, we present the impacts of low exemption age on vehicle fleet, pollution, and infant health compared to a *de facto* no exemption policy. From Panel A, we observe that border municipalities under the 10-year threshold and in the 15- to 20-age cutoff group have an average vehicle age, respectively, 1.05 and 0.46 year higher than border municipalities that do not have exemption age policies. The elevated average fleet age in these localities is also associated with a higher proportion of vehicles above the exemption age. In localities with 10-year cutoff, vehicles 11 years and older represent 6.4 percentage points more of the fleet than comparable localities without exemption. Vehicles older than 10 years are also more prevalent (2.07 p.p.) for municipalities in the 15-20 exemption group, which is consistent with postponing the scrapping decision for vehicles due to expected lower future ownership costs. We also observe that the two low-age exemption policies have more similar effects on the share of vehicles 21 years or older, which are exempt from tax under both policies, with a 3.0 p.p. increase for the lowest-age exemption group and a 2.0 p.p. increase for the 15-20 exemption group relative to the baseline.

Although low-exemption age policies are justified with an argument of increasing affordability of vehicle ownership for relatively lower income households, we do not find evidence to

[23] Controlling for region fixed effects and latitude-longitude polynomials is motivated by the presence of substantial regional heterogeneity in Brazil. To illustrate that we present the distribution of state median ages in Appendix Table B.1.

support this hypothesis. The number of vehicles per capita does not change significantly across borders with different exemption policies. This scenario, where a low exemption age does not impact the rate of vehicle ownership but promotes an older fleet, is consistent with an argument where only individuals who would have vehicles regardless of exemption benefit from the policy via (expected) reduced taxation. Further evidence of changes in the age distribution of the fleet is presented in the Appendix Table D.1, suggesting reduced ownership of tax paying vehicles and increased ownership of tax exempt ones, with no significant changes in total ownership.

Changes in the age distribution of a fleet are the result of the characteristics of the vehicles subject to two types of decisions: trading, and scrapping. Locally, an older fleet can arise from: i) a reduced scrappage rate, and ii) fleet "imported" to the municipality is relatively older than the fleet "exported". Due to data limitations we cannot observe separately, at each age, the amount of vehicles that are being kept, vehicles that are traded, and vehicles scrapped. However, in Appendix Table D.2 we explore the resulting dynamic by observing the effects of exemption policies on changes to the number of vehicles in different vintage groups over a 1-year period. We find evidence that, for the lowest exemption group, very-new vehicles are held over relatively less in the municipality (less net "imported" or more scrapped). Municipalities with low-exemption policies keep more (net "import" more or scrap less) vehicles of older vintage, with a larger effect for the lowest exemption group.

Given advancements in technology for fuel and emissions efficiency and decreasing efficiency of catalytic converters with use, older vehicles are on average more polluting than newer ones. In Panel B of Table 1, we see that policies with low exemption age increase emission intensity of global and local pollutants, with potential detrimental impacts on population health. On average, municipalities with an exemption cutoff age at 10 years have 22% higher on-road $CO2$ emissions per capita, contributing globally to climate change, and 20% higher on-road $NOx$ emissions per capita compared to the baseline group, adding to the formation of smog and ozone concentration locally. The effects from a 15-20 cutoff policy on $CO2$ and $NOx$ emissions intensity are nonsignificant, but point estimates are also positive. Additionally, satellite-level data on concentration of $PM_{2.5}$ indicate, approximately, a 4% ($0.3\mu g/m^3$ ) higher concentration for municipalities in low-exemption-age states. Similarly, satellite measures indicate a 6.9% and 8.1 higher concentration of $CO$ compared to baseline among municipalities with a 10- and a 15-20 cutoff policy, respectively.

In Table 1, Panel C, we observe that infant health outcomes are worse when mothers live in municipalities subject to low exemption age policies. We observe that a low exemption age is associated with lower average 5-minute Apgar score, especially for the group with the cutoff

Table 1: Main Results on Fleet, Pollution, and Infant Health

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| *Panel A*: Vehicle Fleet | | | | |
| Dependent Variables: | Average Vehicle Age | Vehicles 11y+ (%) | Vehicles 21y+ (%) | Vehicles per capita |
| Exemption Age: 10 | 1.05*** | 6.40*** | 3.00*** | 0.021 |
| | (0.254) | (1.28) | (0.722) | (0.025) |
| Exemption Age: 15-20 | 0.46*** | 2.07*** | 2.02*** | -0.010 |
| | (0.162) | (0.777) | (0.519) | (0.017) |
| *Regression Statistics* | | | | |
| Mean Dep. Variable: | 12.1 (year) | 43.1 (%) | 17.9 (%) | 0.45 |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.847 | 0.824 | 0.827 | 0.819 |
| Exemption 10 = 15-20 ($F$) | 8.44*** | 16.99*** | 3.19* | 2.97* |
| *Panel B*: Pollutants | | | | |
| Dependent Variables: | Log CO2 pc (Road) | Log NOx pc (Road) | Log PM2.5 | Log CO |
| Exemption Age: 10 | 0.227* | 0.201* | 0.038* | 0.069** |
| | (0.114) | (0.119) | (0.020) | (0.030) |
| Exemption Age: 15-20 | 0.056 | 0.078 | 0.044*** | 0.081*** |
| | (0.071) | (0.094) | (0.014) | (0.025) |
| *Regression Statistics* | | | | |
| Mean Dep. Variable (Log): | -0.32 | -5.61 | 2.00 | 4.69 |
| Mean Dep. Variable (Level): | 1.01 ($t$ per capita) | 0.006 ($t$ per capita) | 7.78 ($\mu g/m^3$) | 114 (ppbv) |
| Observations | 18,942 | 18,944 | 19,357 | 19,357 |
| $R^2$ | 0.628 | 0.619 | 0.924 | 0.827 |
| Exemption 10 = 15-20 ($F$) | 3.75* | 2.66 | 0.25 | 0.90 |
| *Panel C*: Infant Health | | | | |
| Dependent Variables: | Average 5-min Apgar | Low Birth Weight | Very Low Birth Weight | 28 Days Infant Mortality |
| Exemption Age: 10 | -0.177*** | 7.78*** | 2.45*** | 0.65* |
| | (0.056) | (1.19) | (0.387) | (0.355) |
| Exemption Age: 15-20 | -0.075** | 2.06** | 0.233 | 0.14 |
| | (0.031) | (0.986) | (0.237) | (0.130) |
| *Regression Statistics* | | | | |
| Mean Dep. Variable: | 9.36 | 81.20 (per 1000) | 12.80 (per 1000) | 7.96 (per 1000) |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.354 | 0.269 | 0.140 | 0.100 |
| Exemption 10 = 15-20 ($F$) | 4.90** | 75.00*** | 55.23*** | 2.41 |

*Notes:* Clustered State-Border standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

at 10 years. Mothers from municipalities under a 10-year threshold policy present a 7.78 higher rate of low birth weight (under 2,500 grams) per 1,000 live births than mothers from comparable municipalities with *de facto* no exemption, and have a very-low birth weight rate that is higher by 2.45 per 1,000 live births. In the case of 15-20 years cutoff, low birth weight rates surpass the baseline by 2.06 per 1,000 live births, but effects are not significant for very low birth weight. We also find that the lowest exemption age group has a higher 28-day infant mortality rate, with more 0.65 infant deaths in the first 28 days after birth per 1,000 on average.

In analyzing the heterogeneous effect of low exemption age policies for relatively poorer municipalities in Table 2 we find that while the low exemption policies present similar effects on

Table 2: Heterogeneity: GDP per capita – Municipalities above and at the lowest tercile

| | Vehicle Fleet | | Log Emissions | | Infant Health | |
|---|---|---|---|---|---|---|
| Dependent Variables: | Average Age | Vehicles per capita | CO2 (Road) | NOx (Road) | 5-min Apgar | Low Birth Weight |
| Model: | (1) | (2) | (3) | (4) | (5) | (6) |
| Exemption Age: 10 | 0.580** | 0.005 | 0.139 | 0.099 | -0.176*** | 7.68*** |
| | (0.244) | (0.023) | (0.113) | (0.119) | (0.063) | (1.40) |
| Exemption Age: 10 × Lowest GDPpc Tercile | 0.793** | -0.008 | -0.014 | -0.026 | -0.020 | -1.46 |
| | (0.335) | (0.024) | (0.109) | (0.154) | (0.059) | (2.13) |
| Exemption Age: 15-20 | 0.528*** | -0.004 | 0.096 | 0.132 | -0.070** | 2.31** |
| | (0.156) | (0.015) | (0.066) | (0.090) | (0.030) | (0.940) |
| Exemption Age: 15-20 × Lowest GDPpc Tercile | -0.515* | -0.046*** | -0.266*** | -0.340*** | -0.022 | -1.58 |
| | (0.306) | (0.016) | (0.086) | (0.119) | (0.039) | (1.58) |
| *Regression statistics* | | | | | | |
| Observations | 19,357 | 19,357 | 18,942 | 18,944 | 19,357 | 19,357 |
| $R^2$ | 0.852 | 0.828 | 0.641 | 0.630 | 0.354 | 0.270 |
| Above Lowest Tercile: Exemption 10 = 15-20 ($F$) | 0.09 | 0.24 | 0.22 | 0.15 | 3.64* | 28.12*** |
| At Lowest Tercile: Exemption 10 = 15-20 ($F$) | 26.50*** | 7.38*** | 22.63*** | 16.91*** | 4.11** | 19.78*** |
| At Lowest Tercile: Exemption 10 = 0 ($F$) | 17.29*** | 0.02 | 2.07 | 0.40 | 9.60*** | 12.36*** |
| At Lowest Tercile: Exemption 15-20 = 0 ($F$) | 0.002 | 8.76*** | 5.68** | 4.30** | 3.67* | 0.21 |

*Notes:* Clustered State-Border standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

fleet and pollution among most municipalities, they diverge systematically for the poorest ones, in the bottom third of the GDP per capita distribution.[24] We observe that for municipalities in the lowest tercile with exemption at 10 years the average vehicle age is 0.57 years older compared to the remaining municipalities under the same policy. Conversely, under a 15-20 exemption threshold policy, the increase in average vehicle age disappears for municipalities in the lowest tercile. Moreover, specifically for municipalities in the lowest tercile under the 15-20 exemption policy, we find a decrease of 0.04 vehicles per capita compared to less poor localities under the same policy, a suggestive evidence against the argument that exemptions could increase vehicle ownership for poorer households. In line with the heterogeneous effect on the fleet, poorer municipalities under a 15-20 exemption policy do not present an increase in on-road CO2 and NOx emissions compared to the no-exemption group, while the increase in on-road emissions for the lowest exemption group is similar across GDP per capita levels. Moreover, poorer municipalities do not present significant interaction effect from exemption policies for infant health outcomes.

We include additional analysis in the Appendix for estimates of exemption policies on different pollution and infant health variables, and difference of impacts across layer groups. Appendix Table D.3 show that MERRA-2 satellite-based estimates of total ozone concentration and carbon monoxide emissions are in line with higher pollution levels in low-exemption-age localities. We also show that these anti-scrappage policies impact overall average birth weight, notably with stronger negative effects for births from black mothers. In Appendix Table D.5 we do not find significant differences in vehicle fleet age across layer groups.

[24]We present the heterogeneity analysis for municipalities above and below the median of GDP per capita in the Appendix Table D.4 with similar results.

In addition, we conducted an analysis using alternative methodologies. In Appendix Table D.6 and Appendix Figure D.1 we explore border differences using a regression on discontinuity design, comparing separately borders the three types of policy differences. Using CCT-optimal bandwidth selection (Calonico et al., 2014), we find evidence of higher average vehicle age in municipalities with the 15-20 years thresholds within a narrow distance from a border with a state with *de facto* no exemption policy. We also find a discrete jump in average vehicle age when crossing a border from a state with a 15-20 age cutoff into a state with exemption at 10 years. Furthermore, exploiting Goias (GO) changes in policy in 2015 (increase from 10 to 15 years) and in 2018 (decrease from 15 back to 10), we observe from an event-study analysis that the average vehicle age increases in the period of the higher exemption age, indicating changes in consumer behavior in response to the policy change.

# 6 Political Economy Implications

Despite reducing the states' tax base and distorting incentives of consumers with negative environmental and health effects, anti-scrappage policies – including, specifically, vehicle-age exemptions – remain in place in most Brazilian states. Political incentives of local actors are an important component for the establishment and maintenance of these state-level policies. If the median voter has a preference for lower (expected) tax burden on older vehicles over perceived potential benefits of additional public goods, the electoral system will tend to reward anti-scrappage policies. This can further entrench the tax exemptions as the older fleet grows in share, and might induce a political climate trap (Delfgaauw and Swank, 2024).

In this Section we use the available data on state elections and fleet characteristics to provide suggestive evidence on the political consequences of weakening these anti-scrappage policies. Being set at the state level, changes on the exemption age to the Vehicle Ownership Tax are set via law approved at the state legislative assembly, but can be proposed by either the executive (governor) or legislative (state representatives) branches.[25] We study the electoral impacts on the following election cycle for incumbents responsible for an increase in the exemption age, by observing how the age composition of local fleets impact the vote share on the governor and the state representatives from the governor's party in the state of Mato Grosso do Sul (MS). This policy change was proposed by the governor (Reinaldo Azambuja) and approved at the state assembly with the support of representatives of his party (PSDB).[26]

[25] Governors have veto power over state laws, but vetoes are sent back to the legislative assembly and can be overridden.

[26] State legislative assembly news of the law approval: https://al.ms.gov.br/Noticias/68876/aprovado-projeto-que-isenta-do-ipva-veiculos-com-mais-de-20-anos-de-uso.

During our analysis period, three states increased the age threshold for tax exemption: Mato Grosso do Sul (MS) raised the cutoff from 15 to 20 years, Goias increased the age from 10 to 15 years, and Tocantins (TO) went from a 15 year exemption to a no-age-exemption policy, all in 2015 taking effect in 2016. However, only in MS are we able to observe the same governor that weakened the anti-scrappage policy to run for reelection. The governor of GO reverses policy in 2018, returning to a 10-year cutoff, and, being term-limited for governor, makes a bid for the Senate and loses the election. In the case of TO, the incumbent governor during the policy change is removed from office by the Electoral Supreme Court in 2018 in the midst of an investigation of past campaign financing irregularities, an event followed by a low-turnout special election for the remaining of the term.

## 6.1 Regression Specifications

Using first-round electoral results from the 2014 and 2018 state elections, as described in Section 3, we construct four datasets at the candidate-municipality level to analyze the electoral impacts of raising the exemption age. The first data set includes the electoral outcomes of the incumbent party candidate in the MS governor election for each year across all municipalities in the state. This is used to compare the electoral results of Nelson Trad Filho (PMDS's 2014 candidate) against Reinaldo Azambuja (PSDB's 2018 candidate and incumbent). The second data set follows the first one but includes only Reinaldo Azambuja's outcomes in both elections. The third data set includes the results of incumbent state representatives in all municipalities of the state of MS, which we use to compare the difference in outcomes across the two cycles from candidates who are part of the incumbent governor's party and ones who are not. In the fourth data set we observe the outcomes of incumbent state representatives from incumbent governors' party from the states of MS and SP across municipalities in the MS-SP border pair.

For the first two analysis, comparing the electoral outcomes for the MS governor's elections, we use the following econometric model:

$$y_{m,t} = \alpha R_{S,t} + \pi Veh_{m,t} + \gamma R_{S,t} \times Veh_{m,t} + X'_{m,t}\vartheta + \eta_m + \delta_t + \varepsilon_{m,t}. \tag{2}$$

Our outcome variable of interest $y_{m,t}$ is the percentage of votes for the incumbent party candidate in the municipality $m$ in the election year $t$. The variable $R_{S,t}$ is a dummy that captures if the governor in the state $S$ raised the age of tax exemption during the term (past 4 years). $Veh_{m,t}$ represents different variables used to capture the age composition of the local vehicle fleet. Our main coefficient of interest is represented by $\gamma_1$, capturing the interaction

effect of post policy change election and fleet age composition. We control for municipality ($\eta_m$) and year ($\delta_t$) fixed effects, which should capture a municipality's average votes on an incumbent party candidate and an election cycle statewide variation on the incumbent party candidate. $X'_{m,t}$ includes the municipality-year varying controls from our full specification in the border-pair analysis. A municipality-year-specific error term is represented by $\varepsilon_{m,t}$.

For the incumbent state-representatives analysis, we adjust the model to account for multiple candidates each cycle. Additionally, we include political party fixed effects and interaction terms for being part of the governor's party. The main coefficients of interest in this case are the triple interactions across being in the aftermath of a policy change in the state, being part of the incumbent governor's party, and a measure of local fleet age composition.

## 6.2 Electoral Results

Table 3: Political Economy Implications of Increasing Exemption Age Threshold

| Dependent Variable: | Percentage of Votes on Candidate | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Governor | | | | State Reps. (Interaction w/ Governor Party) | | | |
| | MS - Inc. Party | | MS - Azambuja | | MS | | MS v. SP | |
| Model: | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Raised × Vehicles Under New Exemption (%) | -1.23** | | -1.12*** | | -0.104** | | -0.166** | |
| | (0.472) | | (0.254) | | (0.045) | | (0.073) | |
| Raised × Vehicles Under Old Exemption (%) | | -1.19** | | -1.08*** | | -0.096 | | -0.372*** |
| | | (0.471) | | (0.261) | | (0.067) | | (0.095) |
| Raised × Vehicles Lost Exemption (%) | | -1.90 | | -1.14 | | -0.005 | | -2.08** |
| | | (2.61) | | (1.45) | | (0.378) | | (0.737) |
| *Regression statistics* | | | | | | | | |
| Observations | 174 | 174 | 174 | 174 | 5,133 | 5,133 | 4,129 | 4,129 |
| $R^2$ | 0.949 | 0.949 | 0.973 | 0.973 | 0.135 | 0.135 | 0.173 | 0.174 |

*Notes:* Observations are at a municipality-candidate level. Regressions (1) through (4) contain observations of vote shares on the selected governor candidates, while regressions (5) through (8) include vote shares on incumbent state representatives regardless of party affiliation. Coefficients in regressions (3) through (6) represent the interaction effect with State Representative belonging to the Governor's Party. Regressions (7) and (8) has a sample composed by paired municipalities between states MS and SP. Municipality-level clustered standard-errors in parentheses. All regressions are weighted by municipality-share of total votes in state. All regressions include municipality, year, and party fixed effects in addition to our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

In Table 3 we observe the electoral impacts faced by candidates linked to raising the age exemption threshold for the Vehicle Ownership Tax in the state of Mato Grosso do Sul (MS). In column (1) we see a decrease in the percentage of votes received by an incumbent party candidate after increasing the age cutoff that is associated with the portion of the municipality's fleet that is impacted by the tax. Compared to the election results of the previous incumbent party candidate, the governor received on average 1.23 percentage of votes less for an additional percent of vehicle under the exemption age threshold. Nevertheless, by bundling all vehicles that are under the exemption threshold at the election year we are joining groups that are affected differently by this policy change. Owners of vehicles that

are under the previous age cutoff would be paying the tax regardless of policy change but are impacted via present-value of an extended period of future tax costs. On the other hand, owners of vehicles that would have had some period of tax exemption between the policy change and the election had a direct increase on the vehicle ownership cost due to the taxation, such that one expects the policy change to be more salient to this group. In column (2) we look at the distinguished reactions from these two groups. We see that the aggregated effects are mainly driven by vehicles under the old exemption age, as they are a higher proportion of the fleet. The effect is numerically larger for the interaction with percentage of vehicles that lost exemption but are nonsignificant due to much higher standard errors. In columns (3) and (4) we see that the results are robust to a within-candidate comparison by repeating the exercise but using Reinaldo Azambuja's outcomes in the two election cycles.

In columns (5) through (8) we see that governor's party state representative incumbent candidates also tend to be punished at the ballot after increasing the exemption age threshold. In column (5), comparing governor's party incumbent state representatives against other incumbent candidates, we see that for each additional percentage of vehicle under the new exemption in a municipality there is an associated decrease of 0.10 percentage points on the votes for each governor's party candidate. In columns (7) and (8) we include municipalities in the border pair of the states of MS and SP, both controlled by the same political party in most of the 2015-2018 period, so that we can compare the performance of incumbents from the same party when they have increased the exemption age (MS) and when they have maintained it fixed (SP). [27] For each additional vehicle under the exemption age, we see that incumbent state representatives receive on average 0.17 p.p. less votes in MS after raising the exemption cutoff compared to same-party incumbents across the border in SP without policy change. These effects seem to magnify when breaking apart the proportion of vehicles under the old exemption cutoff and the proportion of vehicles that lost exemption, with a 2 p.p. decrease in votes for PSDB's incumbent candidates for each additional percent of vehicles that lost exemption in MS compared to same-party incumbents in neighboring SP.

Due to our data and setting limitations, we deem these results simply as suggestive evidence of the political costs of weakening anti-scrappage policies. However, the results are in line with evidence of electoral punishment from local tax increases (Donovan et al., 2024).[28] Our findings also dialogue with broader discussions on the political obstacles and costs for more

[27] Although being controlled by the same party (PSDB) during most of the 2015-2018 period, the SP governor, Geraldo Alckmin, leaves office in April of 2018 to campaign for President, leaving the position to the vice-governor Márcio França (PSB) for the remainder of the year.

[28] The observed timing of exemption age increases, usually at the beginning of a gubernatorial term, also suggests potential election cycles in taxation (Fuest et al., 2024).

environmentally efficient taxation, notably fuel and energy taxation (Hammar et al., 2004; Agostini and Jiménez, 2015; Carattini et al., 2017).

# 7 Concluding Remarks

Transportation is one of the main sources of greenhouse gases and pollution emissions worldwide. Although most of the regulations on vehicle emission standards focus on new vehicles, the majority of motor vehicle pollution comes from vehicles older than 10 years. This issue can be magnified in the presence of existing policies that de-incentivize renewal of the fleet, which is the case of vehicle property taxes or registration fees that decrease with vehicle age. Brazil's Vehicle Ownership Tax is a prime example of this type of policy with vehicles older than an state-set age cutoff being exempt from the tax.

In this study we utilize a border-pair approach to identify the effect of different state's exemption age thresholds to the vehicle tax. We find that different exemption age policies have different effects on the fleet, with the lowest exemption age distorting the fleet age the most. While an exemption age cutoff between 15-20 years increases the average vehicle age by approximately 0.5 year on average, a cutoff at 10 years raises the fleet age by a full 1 year. We also find evidence of an increase in pollution emissions and concentration in municipalities close to the state borders under a low exemption age policy. Furthermore, these distortions are also reflected in deteriorated infant health outcomes, which can be a result of increased pollution and other indirect effects of state policies.

Contrasting with the argument that these policies would be directed to increase affordability of vehicle ownership to lower income households, we do not find impacts on the number of vehicles per capita. Different exemption age policies seem to have divergent impacts in the poorest municipalities: while we see an exceptionally higher fleet age increase among municipalities in the lowest exemption group, we find no age increase for the poorest municipalities in the 15-20 exemption cutoff group, which could indicate a lower "take-up" for this group.

Our results are consistent with a scenario where owners extend life-cycle of vehicles, obtaining tax benefits, but vehicle ownership is unchanged. This indicates the policy fails to achieve their equity goals, working similarly to a transfer to the group that would own older vehicles regardless of exemption, while adding local and global negative externalities. Nevertheless, the private benefits of these exemptions make them politically costly to be overturned, with incumbents being electorally punished when raising exemption thresholds.

Concluding, even though age exemption policies can be a popular feature of the present

tax system in many Brazilian states, there are more downturns to this policy than only tax revenue foregone, as we help inform in this paper. Policy-makers need to be conscious of the pollution and downstream health impacts of lower exemptions. Moreover, policy-makers should also consider past tax reforms around the world that have shown that vehicle tax rates linked to automobiles' emission efficiency have impacts in reducing pollution levels.

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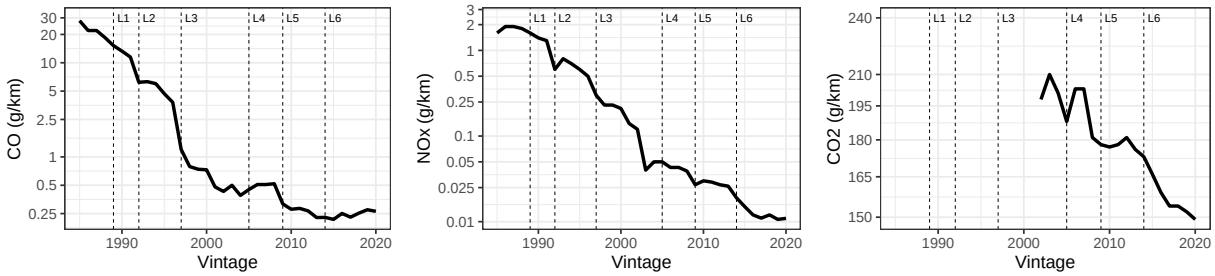
# A Institutional Background Appendix

Table A.1: PROCONVE – Automobile Emissions Standards

| PROCONVE Standard | Period | CO | HC | NOx | NMHC |
|---|---|---|---|---|---|
| Panel A: Light Duty Vehicles Emissions ($g/km$) | | | | | |
| L1 | 1989 – 1991 | 24.0 | 2.1 | 2.0 | - |
| L2 | 1992 – 1996 | 12.0 | 1.2 | 1.4 | - |
| L3 | 1997 – 2004 | 2.0 | 0.3 | 0.6 | - |
| L4 | 2005 – 2008 | 2.0 | - | 0.6 | 0.16 |
| L5 | 2009 – 2013 | 2.0 | - | 0.12 | 0.05 |
| L6 | 2014 – 2021 | 1.3 | - | 0.12 | 0.05 |
| Panel B: Heavy Duty Vehicles Emissions ($g/kWh$) | | | | | |
| P1 (Voluntary) | 1990 – 1992 | 14.0 | 3.50 | 18.0 | - |
| P2 | 1993 – 1995 | 11.2 | 2.45 | 14.4 | - |
| P3 | 1996 – 1999 | 4.9 | 1.23 | 9.0 | - |
| P4 | 2000 – 2005 | 4.0 | 1.10 | 7.0 | - |
| P5 | 2006 – 2008 | 2.1 | 0.66 | 5.0 | - |
| P6 | 2009 – 2011 | 1.5 | 0.46 | 3.5 | - |
| P7 | 2012 – 2021 | 1.5 | 0.46 | 2.0 | - |

*Notes:* In Panel A, emission standards are for gasoline light duty vehicles. Stage L4 had a progressive rule: in 2005 it should include 40% of annual production of light duty vehicles, in 2006 it should include 70% of annual production, and full compliance starting in 2007. In Panel B, starting with P5 diesel vehicles are tested have thresholds for ESC and ETC tests, we present the limits for the ESC tests. In P2 and P3 city buses were required to adhere to the new stages two years before the general fleet. Stage P6 was *de facto* never enforced (because low sulfur fuel was not available), with P5 remaining in effect until 2011.

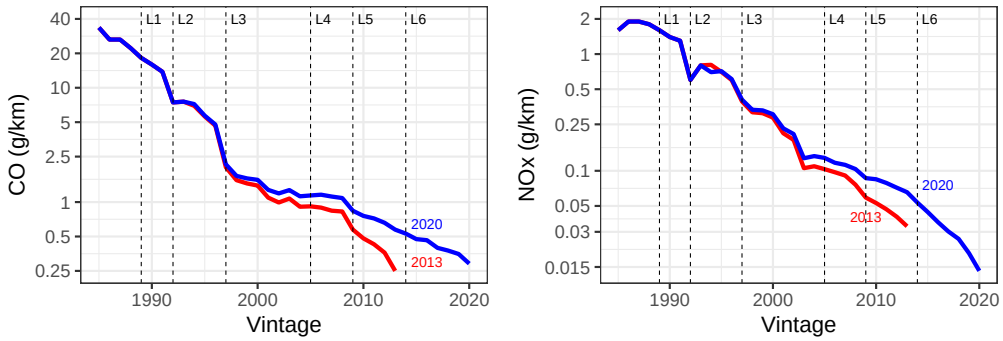
Figure A.1: CETESB – New Gasoline-Powered Light-Duty Vehicles Emissions




(a) CO (b) NOx (c) CO2

*Notes:* All graphs are in log-scale for readability. Dashed vertical lines represent vintages for which new LDV emission standard becomes effective. Data is retrieved from CETESB's new vehicles emission factor data, with values indicating average emission factor from each vehicle's vintage weighted by models' sales shares in that vintage. Values before 2003 correspond to the average emissions for new "gas-powered only" vehicles. From 2003 onward all values correspond to average emissions for new "flex-fuel" vehicles (gas and ethanol -fueled) when powered with gas.

Figure A.2: CETESB – Vehicle Vintage Deteriorated-Emissions, for Gasoline-Powered Light-Duty Vehicles



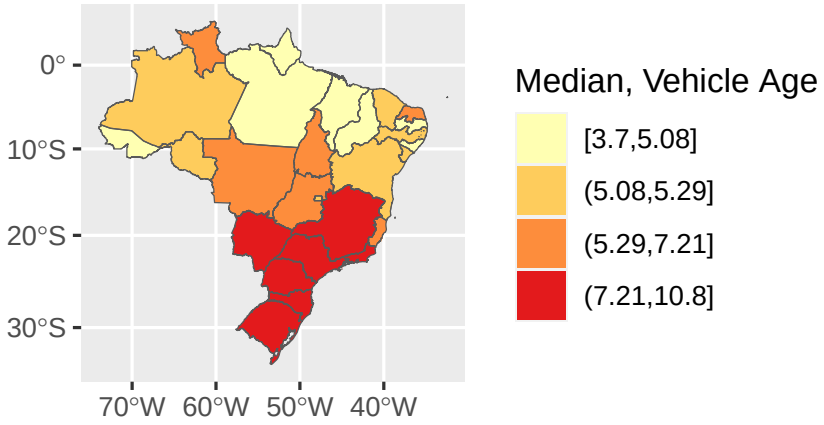

(a) CO (b) NOx

*Notes:* All graphs are in log-scale for readability. Dashed vertical lines represent vintages for which new LDV emission standard becomes effective. Data is retrieved from CETESB's estimates for vehicles' deteriorated emissions factors, with values indicating average deteriorated-emissions from each vehicle's vintage weighted by models' sales shares in that vintage. Deteriorated emissions take into account the degradation of vehicles' emissions controls with age and usage. Deteriorated emissions are calculated by adding a emission-deterioration factor to the base new vehicle emission for each 50,000 miles-traveled. Emission-deterioration factors start to be calculated by CETESB in 2003 with lab durability experiments, vintages from 1995 to 2002 were assigned the same factors as lab-obtained measures from the 2003-2007 period, for vintages before 1995 it was considered no NOx deterioration and a flat 20% deterioration for CO emissions after an 100,000 miles threshold. Values for vintages before 2003 correspond to vintage-average deteriorated emissions for "gas-powered only" vehicles. From 2003's vintage onward all values correspond to vintage-average deteriorated emissions for new "flex-fuel" vehicles (gas and ethanol -fueled) when powered with gas.

# B Data Appendix

## B.1 Vehicle Data

Figure B.1: Regional Heterogeneity in Median Vehicle Age, 2013




*Notes:* Each color represents a quartile in the distribution of state median vehicle ages in 2013.

Table B.1: 2013 Fleet by PROCONVE Standard associated to their Vintage

| | | 2013 Total RENAVAM Fleet from Vintage | | | |
|---|---|---|---|---|---|
| | | | Shares in Exemption Groups: | | |
| LDV Standard | Vintage | Quantity (Millions) | 10 | 15-20 | "No" Exemption |
| Before L1 | - 1988 | 11.29 | 0.11 | 0.14 | 0.14 |
| L1 | 1989 - 1991 | 2.61 | 0.02 | 0.03 | 0.03 |
| L2 | 1992 - 1996 | 7.63 | 0.08 | 0.10 | 0.09 |
| L3 | 1997 - 2004 | 17.72 | 0.22 | 0.22 | 0.21 |
| L4 | 2005 - 2008 | 15.82 | 0.21 | 0.19 | 0.20 |
| L5 | 2009 - 2013 | 25.95 | 0.34 | 0.31 | 0.33 |

*Notes:* This Table presents the total amount of vehicles in the RENAVAM database in 2013 with a vintage associated with the period of each PROCONVE's Light Duty Vehicle Emission Standard. In our dataset we cannot disaggregate at the same time quantity of vehicle by vintage and vehicle type. In 2013, light duty vehicles – that are targeted by the PROCONVE L-standards – corresponded to 55% of the total fleet.

## B.2 Summary Statistics

Table B.2: Summary Statistics National vs. Layers

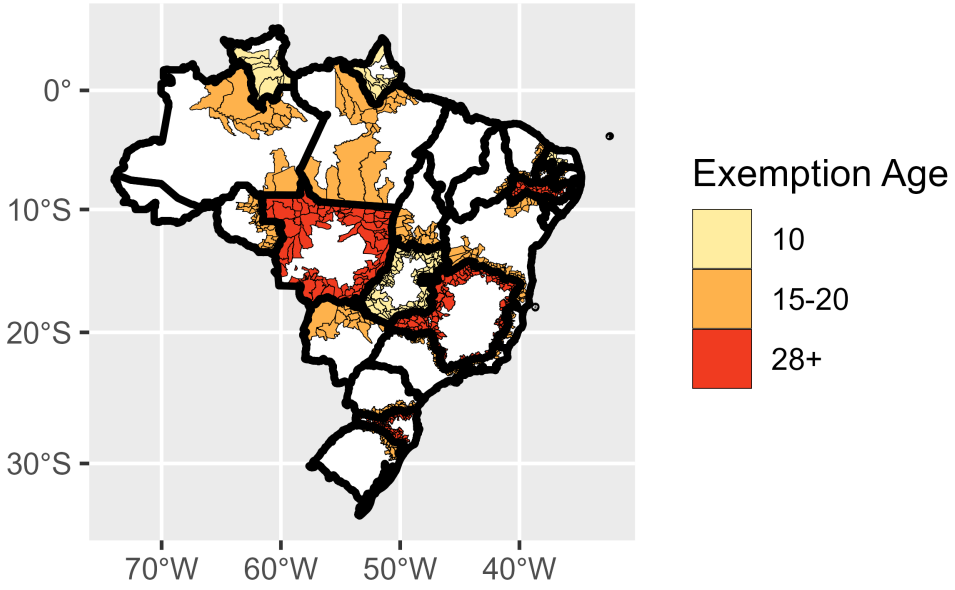
| | (1) All | (2) Layers (1-2) | (3) Not in Layers | (4) (2) - (3) |
|---|---|---|---|---|
| *Panel A:* General Characteristics | | | | |
| 2010 Population (by 1,000) | 34.28 | 24.51 | 41.84 | -17.33* (7.59) |
| GDP per capita (1,000 BRL) | 15.61 | 14.32 | 16.61 | -2.29 (1.58) |
| Centroid Distance to Border (Miles) | 58.35 | 26.20 | 83.24 | -57.03*** (4.58) |
| Area in 1,000 km$^2$ | 1.62 | 2.48 | 0.95 | 1.53*** (0.57) |
| *Panel B:* Fleet | | | | |
| Average Vehicle Age | 13.38 | 12.58 | 14.00 | -1.42*** (0.42) |
| Vehicles 0-10 (%) | 51.58 | 54.73 | 49.15 | 5.57*** (1.59) |
| Vehicles 11+ (%) | 48.42 | 45.27 | 50.85 | -5.57*** (1.59) |
| Vehicles 11-20 (%) | 26.60 | 26.11 | 26.99 | -0.88** (0.38) |
| Vehicles 21+ (%) | 21.81 | 19.16 | 23.86 | -4.70*** (1.40) |
| Vehicles per capita | 0.40 | 0.36 | 0.43 | -0.07** (0.03) |
| Fleet Size (by 1,000) | 17.04 | 10.96 | 21.75 | -10.79** (4.87) |
| *Panel C:* Pollution | | | | |
| $PM_{2.5}$ Concentration ($\mu g/m^3$) | 7.59 | 7.46 | 7.68 | -0.22 (0.37) |
| $CO$ Concentration ($ppbv$) | 114.51 | 107.22 | 120.15 | -12.92 (8.05) |
| $CO2$ On-road Emissions ($1,000t$) | 31.98 | 24.93 | 37.45 | -12.51** (6.03) |
| $NOx$ On-road Emissions ($t$) | 184.07 | 150.96 | 209.70 | -58.73* (33.03) |
| $CO2$ On-road Emissions ($t$) per capita | 0.99 | 0.92 | 1.04 | -0.12 (0.08) |
| $NOx$ On-road Emissions ($t$) per capita | 0.006 | 0.006 | 0.007 | -0.001 (0.001) |
| Mining Activity | 0.11 | 0.10 | 0.11 | -0.01 (0.02) |
| Fossil Fuel Power Plant | 0.13 | 0.11 | 0.14 | -0.02 (0.02) |
| Biomass Power Plant | 0.08 | 0.08 | 0.07 | 0.008 (0.02) |
| Share of Fire Area | 0.006 | 0.007 | 0.005 | 0.002** (0.001) |
| *Panel D:* Health | | | | |
| Average 5-minutes Apgar Score | 9.38 | 9.37 | 9.38 | -0.01 (0.01) |
| Low Birth Weight (per 1,000) | 80.03 | 76.96 | 82.40 | -5.43*** (1.60) |
| Very Low Birth Weight (per 1,000) | 12.15 | 11.58 | 12.59 | -1.00*** (0.27) |
| 28-Day Infant Mortality (per 1,000) | 7.81 | 7.99 | 7.67 | 0.32* (0.19) |
| Healthcare Facility | 0.54 | 0.56 | 0.53 | 0.02 (0.03) |
| Health Facilities Beds | 90.71 | 58.19 | 115.89 | -57.70*** (20.20) |

*Notes:* Clustered State-level standard-errors in parenthesis. Municipalities are equally weighted in all regressions. Monetary values were adjusted by inflation to 2010 prices.

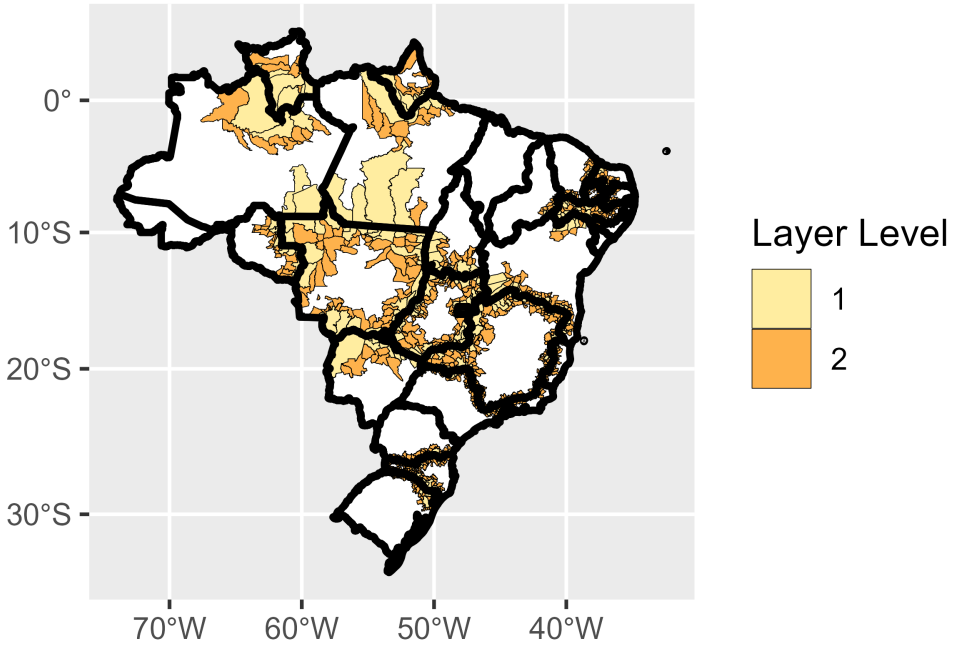
# C Border-Pair Approach Appendix

## C.1 Identification

Figure C.1: Identifying the Effect of Exemption Age: Municipalities paired with Different Exemption Group in 2013, Layers 1-2




(a) Exemption Age Group




(b) Layer Level

Notes: In 2013, identifying variation for the effect of exemption age cutoffs comes from 1,607 municipalities. Breaking down the number of municipalities by exemption age group: (Exemption at 10) 240; (Exemption at 15-20) 726; (Exemption at 28+) 641. Breaking down the number of municipalities by layer level: (Layer 1) 753; (Layer 2) 854. As states change exemption rules following Figure 1 (a), the identifying sample changes over time.

## C.2 Characteristics across borders

Table C.1: Differences in Characteristics and Policies across Paired Borders

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Panel A:* State Policies and Local Infrastructure | | | | | |
| Dependent Variables: | Basic VAT Rate | Gasoline Price | Healthcare Facility | Health Facilities Beds | Interstate Highway |
| Exemption Age: 10 | 0.150 | -0.018 | -0.070* | -919.8 | -0.044 |
| | (0.150) | (0.042) | (0.039) | (607.8) | (0.065) |
| Exemption Age: 15-20 | 0.044 | -0.011 | 0.004 | -35.2 | -0.040 |
| | (0.107) | (0.034) | (0.037) | (97.3) | (0.044) |
| *Regression Statistics* | | | | | |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.784 | 0.876 | 0.133 | 0.702 | 0.131 |
| *Panel B:* Local Economy and Polluting activities | | | | | |
| Dependent Variables: | Log GDP pc | 2010's Log Population | Mining Activity | Fossil Fuel Power Plant | Share Fire Area |
| Exemption Age: 10 | -0.230 | -0.740 | -0.202** | -0.168 | 0.006** |
| | (0.311) | (0.498) | (0.099) | (0.103) | (0.003) |
| Exemption Age: 15-20 | 0.053 | 0.038 | -0.114*** | -0.035 | 0.0006 |
| | (0.041) | (0.171) | (0.038) | (0.031) | (0.0005) |
| *Regression Statistics* | | | | | |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.635 | 0.514 | 0.448 | 0.388 | 0.548 |
| *Panel C:* Geography and Weather | | | | | |
| Dependent Variables: | Distance to Border | Muni Area 1,000km$^2$ | Avg. Temperature | Atmospheric Pressure | Yearly Precipitation |
| Exemption Age: 10 | -10.2** | -2.89 | 0.606*** | 251.8 | -8,398.2 |
| | (3.94) | (2.09) | (0.161) | (225.0) | (6,172.5) |
| Exemption Age: 15-20 | -0.144 | 0.591 | 0.411** | 376.6* | 1,761.6 |
| | (1.51) | (0.680) | (0.163) | (207.8) | (2,004.3) |
| *Regression Statistics* | | | | | |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.726 | 0.587 | 0.940 | 0.771 | 0.588 |

*Notes:* Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include Year-Border-Layer Pair fixed effects, region fixed effects and control for latitude and longitude with quadratic polynomials. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

# D Results Appendix

Table D.1: Impacts in Vehicles per capita by Age Group and Vehicle Age Percentiles

| Model: | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Panel A*: Vehicles per capita by age | | | | | |
| Dependent Variables: | All | 0-10 years | 11+ years | 11-20 years | 21+ years |
| Exemption Age: 10 | 0.021 | -0.009 | 0.031** | 0.014 | 0.017*** |
| | (0.025) | (0.014) | (0.013) | (0.008) | (0.006) |
| Exemption Age: 15-20 | -0.010 | -0.018* | 0.007 | -0.002 | 0.009** |
| | (0.017) | (0.009) | (0.009) | (0.005) | (0.004) |
| *Regression Statistics* | | | | | |
| Mean Dep. Variable: | 0.45 | 0.24 | 0.20 | 0.12 | 0.09 |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.819 | 0.762 | 0.859 | 0.803 | 0.872 |
| *Panel B*: Vehicle age percentile | | | | | |
| Dependent Variables: | Percentile 10 | Percentile 30 | Median | Percentile 70 | Percentile 90 |
| Exemption Age: 10 | 0.276*** | 0.720*** | 1.36*** | 1.90*** | 1.19** |
| | (0.090) | (0.151) | (0.246) | (0.381) | (0.569) |
| Exemption Age: 15-20 | 0.064 | 0.221** | 0.505*** | 0.719*** | 0.755** |
| | (0.051) | (0.087) | (0.163) | (0.250) | (0.318) |
| *Regression Statistics* | | | | | |
| Mean Dep. Variable: | 1.83 | 5.27 | 8.80 | 14.40 | 25.80 |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 19,357 |
| $R^2$ | 0.802 | 0.854 | 0.802 | 0.827 | 0.857 |

*Notes:* Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table D.2: Changes on Number of Vehicles of Given Vintage over 1 year

| Model: | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| *Panel A*: $\Delta$ Vehicles in Vintage Group | | | | |
| Dependent Variables: | 1 year | 1-10 years | 11-20 years | 21+ years |
| Exemption Age: 10 | -891.0* | 389.6 | 562.7** | 26.8 |
| | (468.3) | (244.4) | (276.5) | (30.9) |
| Exemption Age: 15-20 | -75.5 | -34.1 | 142.1** | 19.5 |
| | (89.7) | (127.6) | (55.5) | (18.8) |
| *Regression Statistics* | | | | |
| Mean Dep. Variable: | 1,535.0 | 385.2 | -438.7 | -64.2 |
| Observations | 16,941 | 16,941 | 16,941 | 16,941 |
| $R^2$ | 0.982 | 0.724 | 0.956 | 0.781 |
| *Panel B*: $\Delta$% Vehicles in Vintage Group | | | | |
| Dependent Variables: | 1 year | 1-10 years | 11-20 years | 21+ years |
| Exemption Age: 10 | -3.83*** | 1.74*** | 1.46*** | 0.824*** |
| | (1.39) | (0.483) | (0.409) | (0.262) |
| Exemption Age: 15-20 | -0.061 | 0.726* | 0.746*** | 0.375** |
| | (1.20) | (0.374) | (0.205) | (0.185) |
| *Regression Statistics* | | | | |
| Mean Dep. Variable: | 28.5 | 3.48 | 1.01 | 0.638 |
| Observations | 16,930 | 16,941 | 16,940 | 16,905 |
| $R^2$ | 0.213 | 0.464 | 0.413 | 0.221 |

*Notes:* Changes on vintage group are calculated as the number of vehicles in that age group in period $t$ minus the number of vehicles in $t-1$ that would be in that age group in $t$. This can be broken down for each vintage group as the sum of vehicles kept over the period, net vehicles traded, and minus vehicles scrapped. Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table D.3: Other Pollutants and Infant Health Variables

| | Pollutants - MERRA-2 | | 1-Min Apgar | Weight at Birth | | | |
|---|---|---|---|---|---|---|---|
| | Log O3 (Concentration) | Log CO (Emissions) | | All | Black Mother | Brown Mother | Native Mother |
| Model: | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Exemption Age: 10 | 0.0002 | 0.155 | -0.069 | -23.2*** | -67.0*** | -18.6** | -63.1 |
| | (0.0002) | (0.098) | (0.060) | (7.71) | (20.9) | (7.63) | (66.7) |
| Exemption Age: 15-20 | 0.0004*** | 0.265*** | -0.055** | -4.19 | -11.0 | -8.05* | -43.7* |
| | (0.0001) | (0.075) | (0.023) | (4.91) | (7.91) | (4.53) | (22.4) |
| *Regression statistics* | | | | | | | |
| Mean Dep. Variable: | 5.56 | -21.70 | 8.32 | 3.195 (kg) | 3.171 (kg) | 3.191 (kg) | 3.176 (kg) |
| Observations | 19,357 | 19,357 | 19,357 | 19,357 | 15,798 | 19,166 | 4,516 |
| $R^2$ | 0.990 | 0.566 | 0.326 | 0.470 | 0.106 | 0.242 | 0.317 |
| Exemption 10 = 15-20 ($F$) | 0.56 | 3.75* | 0.06 | 11.62*** | 9.21*** | 2.72* | 0.09 |

*Notes:* Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table D.4: Heterogeneity by GDP per capita, comparing municipalities above and below median

| | Vehicle Fleet | | Log Emissions | | Infant Health | |
|---|---|---|---|---|---|---|
| Dependent Variables: | Average Age | Vehicles per capita | Log CO2 pc (Road) | Log NOx pc (Road) | 5-min Apgar | Low Birth Weight |
| Model: | (1) | (2) | (3) | (4) | (5) | (6) |
| Exemption Age: 10 | 0.680* | 0.015 | 0.233 | 0.167 | -0.107* | 6.67*** |
| | (0.347) | (0.028) | (0.167) | (0.158) | (0.059) | (2.03) |
| Exemption Age: 10 × Below Median | 0.349 | -0.011 | -0.145 | -0.112 | -0.157** | 1.30 |
| | (0.457) | (0.031) | (0.169) | (0.177) | (0.068) | (3.07) |
| Exemption Age: 15-20 | 0.638*** | 0.008 | 0.153* | 0.203* | -0.046 | 2.46** |
| | (0.194) | (0.016) | (0.079) | (0.109) | (0.032) | (1.11) |
| Exemption Age: 15-20 × Below Median | -0.450 | -0.045** | -0.241*** | -0.311** | -0.068* | -1.06 |
| | (0.318) | (0.021) | (0.087) | (0.122) | (0.040) | (1.80) |
| *Regression statistics* | | | | | | |
| Observations | 19,357 | 19,357 | 18,942 | 18,944 | 19,357 | 19,357 |
| $R^2$ | 0.849 | 0.820 | 0.632 | 0.624 | 0.358 | 0.269 |
| Above Median: Exemption 10 = 15-20 ($F$) | 0.02 | 0.08 | 0.27 | 0.07 | 1.45 | 6.67*** |
| Below Median: Exemption 10 = 15-20 ($F$) | 11.19*** | 4.64** | 5.53** | 4.40** | 9.54*** | 24.33*** |
| Below Median: Exemption 10 = 0 ($F$) | 9.09*** | 0.02 | 0.79 | 0.23 | 17.99*** | 17.07*** |
| Below Median: Exemption 15-20 = 0 ($F$) | 0.53 | 2.87* | 1.85 | 1.50 | 7.66*** | 0.82 |

*Notes:* Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table D.5: Heterogeneity: Layer Groups

| | Vehicle Fleet | | Log Emissions | | Infant Health | |
|---|---|---|---|---|---|---|
| Dependent Variables: | Average Age | Vehicles per capita | Log CO2 pc (Road) | Log NOx pc (Road) | 5-min Apgar | Low Birth Weight |
| Model: | (1) | (2) | (3) | (4) | (5) | (6) |
| *Panel A: Layer 1 v. Layer 2* | | | | | | |
| Exemption Age: 10 | 1.02*** | 0.046* | 0.298** | 0.294** | -0.144*** | 6.34*** |
| | (0.244) | (0.027) | (0.131) | (0.125) | (0.052) | (1.23) |
| Exemption Age: 10 × Layer 2 | 0.170 | -0.066** | -0.221 | -0.290** | -0.106** | 4.44** |
| | (0.350) | (0.029) | (0.135) | (0.141) | (0.047) | (1.83) |
| Exemption Age: 15-20 | 0.691** | -0.0007 | -0.016 | -0.019 | -0.116*** | 3.35*** |
| | (0.264) | (0.020) | (0.081) | (0.112) | (0.042) | (1.21) |
| Exemption Age: 15-20 × Layer 2 | 0.384 | 0.018 | -0.116 | -0.156 | -0.068** | 2.08 |
| | (0.297) | (0.016) | (0.081) | (0.099) | (0.033) | (1.26) |
| *Regression statistics* | | | | | | |
| Observations | 19,357 | 19,357 | 18,942 | 18,944 | 19,357 | 19,357 |
| $R^2$ | 0.847 | 0.820 | 0.628 | 0.620 | 0.355 | 0.269 |
| *Panel B: Layers 1-2 v. Layer 3* | | | | | | |
| Exemption Age: 10 | 1.05*** | -0.008 | 0.244** | 0.303*** | -0.200*** | 9.12*** |
| | (0.250) | (0.032) | (0.105) | (0.114) | (0.049) | (1.15) |
| Exemption Age: 10 × Layer 3 | 0.715 | -0.040 | 0.010 | 0.048 | -0.047 | -6.43** |
| | (0.502) | (0.038) | (0.157) | (0.186) | (0.055) | (2.83) |
| Exemption Age: 15-20 | -0.005 | 0.013 | 0.058 | 0.115 | -0.115*** | 2.50** |
| | (0.351) | (0.026) | (0.094) | (0.118) | (0.031) | (1.07) |
| Exemption Age: 15-20 × Layer 3 | -0.323 | 0.018 | 0.024 | 0.047 | -0.026 | -0.617 |
| | (0.297) | (0.018) | (0.089) | (0.118) | (0.032) | (1.16) |
| *Regression statistics* | | | | | | |
| Observations | 27,396 | 27,396 | 26,790 | 26,793 | 27,396 | 27,396 |
| $R^2$ | 0.846 | 0.829 | 0.629 | 0.613 | 0.411 | 0.266 |

*Notes:* Clustered (State-Border) standard-errors in parentheses. All regressions includes 2010 municipal population weights. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

## D.1 RD

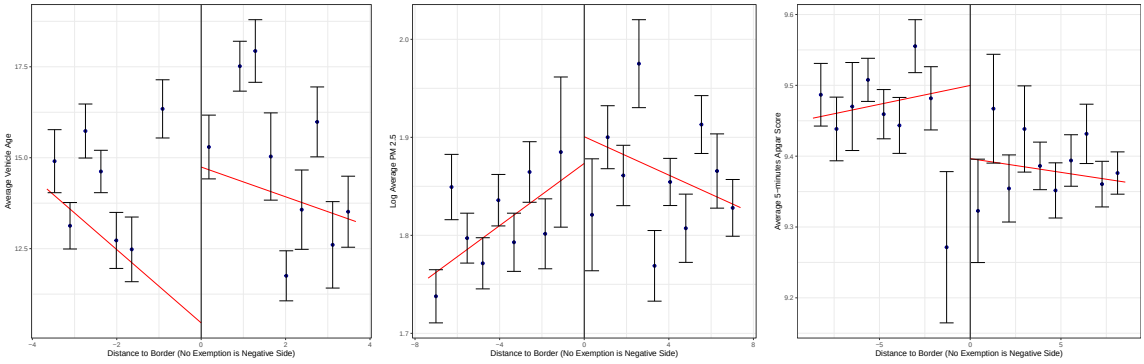
Table D.6: RDD - Border as Discontinuity

| Policy Difference | Vehicle Age | Log PM 2.5 | 5-min Apgar |
|---|---|---|---|
| *Panel A: CCT Robust Bias-Corrected RD* | | | |
| No Exemption v. Exemption at 15-20y | 6.055*** | 0.035** | -0.068*** |
| | (0.477) | (0.014) | (0.020) |
| Bandwidth | 13.63 | 16.82 | 24.18 |
| Observations | 649 | 2330 | 2813 |
| No Exemption v. Exemption at 10y | -2.065** | -0.194*** | -0.458 |
| | (0.871) | (0.055) | (0.755) |
| Bandwidth | 49.806 | 25.029 | 18.806 |
| Observations | 313 | 141 | 59 |
| Exemption at 15-20y v. Exemption at 10y | 2.368*** | -0.296*** | -0.287*** |
| | (0.404) | (0.045) | (0.033) |
| Bandwidth | 38.337 | 30.810 | 33.701 |
| Observations | 1270 | 494 | 1104 |
| *Panel B: Linear Regression RD* | | | |
| No Exemption v. Exemption at 15-20y | 0.923 | 0.127 | -0.055 |
| | (1.41) | (0.085) | (0.087) |
| Bandwidth | 50 | 50 | 50 |
| Observations | 8,384 | 8,384 | 8,384 |
| No Exemption v. Exemption at 10y | -1.09 | 0.071 | 0.244 |
| | (1.24) | (0.041) | (0.128) |
| Bandwidth | 50 | 50 | 50 |
| Observations | 519 | 519 | 519 |
| Exemption at 15-20y v. Exemption at 10y | 2.78** | 0.091 | -0.168** |
| | (1.27) | (0.171) | (0.077) |
| Bandwidth | 50 | 50 | 50 |
| Observations | 1,842 | 1,842 | 1,842 |

*Notes:* Observations are at the municipality-year level and were weighted by their 2010 population measured in the population census. Regressions do not include any controls. Regressions are clusterized at the State-Border level. In Panel A, each estimate is computed using CCT-optimal bandwidth selections (Calonico et al., 2014), using uniform kernels, and distance coefficients are flexible to be different across the border. In Panel B, all estimates have a bandwidth of 50 miles and distance coefficient is constrained to be the same on the two sides of the border.

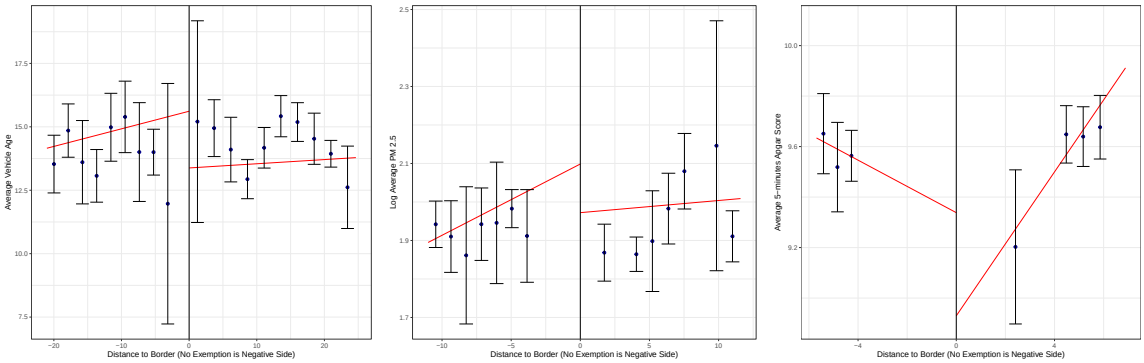
Figure D.1: RDD – Border as a Discontinuity, Local Linear Polynomials with CCT-Optimal Bandwidth

*Panel A:* No Exemption v. Exemption at 15-20 years



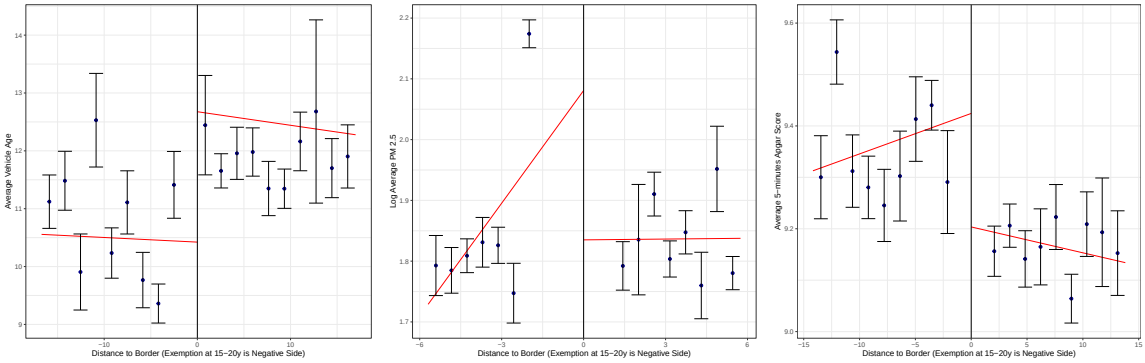

(a) Average Vehicle Age (b) Log $PM_{2.5}$ (c) 5-min Apgar Score

*Panel B:* No Exemption v. Exemption at 10 years




(d) Average Vehicle Age (e) Log $PM_{2.5}$ (f) 5-min Apgar Score

*Panel C:* Exemption at 15-20 years v. Exemption at 10 years

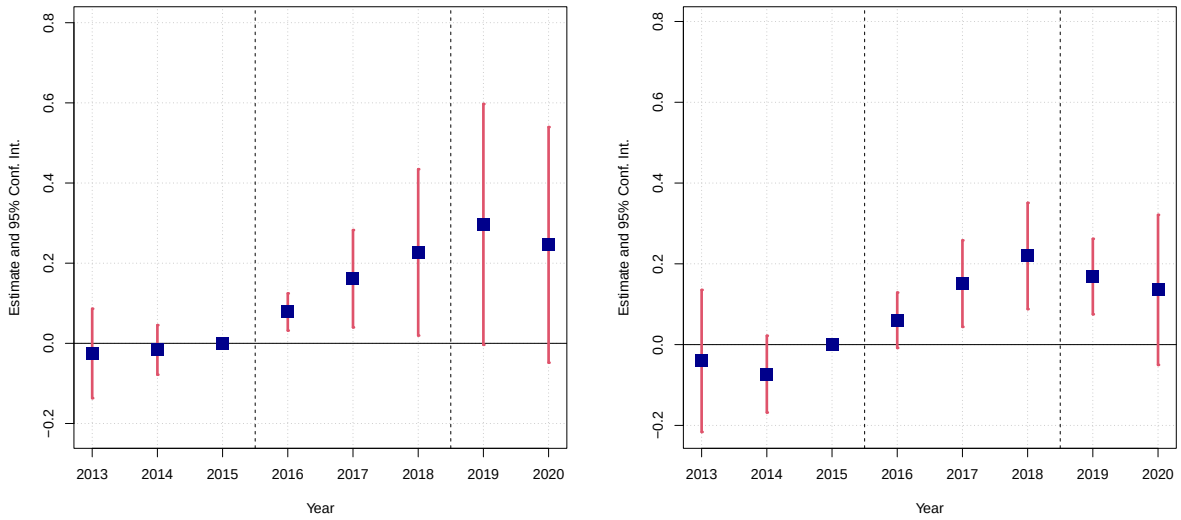



(g) Average Vehicle Age (h) Log $PM_{2.5}$ (i) 5-min Apgar Score

*Notes:* Each estimate is computed using CCT-optimal bandwidth selections (Calonico et al., 2014). Observations are at the municipality-year level and were weighted by their 2010 population measured in the population census. Binned sample means are presented with 95% confidence intervals. No covariates were included.

## D.2 Event-Study

Figure D.2: Event-Study: Average Vehicle Age, Goias (GO) v. No Exemption States




(a) No Controls

(b) With Controls

*Notes:* In this event-study we compare Goias (GO) average vehicle age against the three states that keep no exemption status in all years of our sample: Minas Gerais (MG), Santa Catarina (SC), and Pernambuco (PE). In 2015, Goias increases the exemption age threshold from 10 to 15 years, to take effect in 2016. In 2018, Goias decreases the exemption age threshold from 15 back to 10 years, to take effect in 2019. Blue dots represent the point-estimates, and red lines are the 95% confidence intervals. Errors are clustered at the municipality-level. Observations are at the municipality-year level, and are weighted by the 2010 population. All regressions include municipality and year fixed effects. In (b) we include controls for: presence of mining, share of fire area, total number of beds in health units, log of current and lagged GDP per capita, quadratic polynomials of precipitation, temperature, and atmospheric pressure, as well as interactions of year and index variables for presence of biomass power plant, fossil fuel power plant, interstate highway, and health unit.