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

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Abstract

Transportation is one of the main sources of greenhouse gases and pollution emissions worldwide. Recent studies have shown that the majority of automobile pollution comes from vehicles older than 10 years, with potential negative impacts on public health. Notwithstanding, several existing policies create incentives against removing older vehicles from the fleet. This paper examines the impacts of an anti-scrappage policy in Brazil using a border-pair approach that leverages state variation in exemption age thresholds for the vehicle ownership tax. Using municipality-level vehicle registration data and satellite measures of pollution from 2013-2020, we find that exemption cutoffs from 10 to 20 years can increase local average vehicle age up to 1 year, with an associated 4% higher concentration of $PM_{2.5}$ and up to 50% higher CO2 on-road emissions. Using administrative data on birth records, we find that these policies also have negative impacts on infant health with a 2.8 to 7.5 increase (3.5% to 9.3%) in local low birth weight rates per 1000 live births. Using electoral data from 2014 and 2018 state gubernatorial races, we also find evidence that low age exemptions are 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

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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 emissions from vehicle transportation are generated by older vehicles (Jacobsen et al., 2022), policies worldwide have offered incentives to encourage the continued operation of these vehicles, 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, there may be detrimental effects to public health.

In this paper, we exploit variation in exemption thresholds for vehicle ages 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 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

[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).

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 from the Brazilian Ministry of Transportation, we find that states with lower exemption ages exhibit an average vehicle age 0.5 to 1 year 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.

Our findings also indicate that states implementing relatively low age exemption policies experience elevated local pollution levels, higher greenhouse gases emissions, and poorer birth outcomes, which can be attributed to the age distribution of the vehicle fleet. Leveraging satellite-derived data on pollutants from MERRA-2, we observe that municipalities subject to low-exemption-age policies exhibit, on average, a concentration of fine particulate matter 2.5 (PM2.5) around 4% higher, and a concentration of carbon monoxide between 7.9% and 9.7% higher than the baseline. Based on municipality-level estimates of on-road CO2 emissions from SEEG, we find between a 25% and a 50% increase in emissions normalized by area. 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 -0.06 to a -0.018 decrease), higher rates of low birth weight (ranging from additional 2.9 to 7.6 per thousand live births), and higher rates of 28-day infant mortality (0.6 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. However, besides environmental and health negative impacts, overturning exemption is politically costly. Incumbent state governors that raised exemption age thresholds during the term have, on average, 1.4 less percentage points of votes in border municipalities for each additional percent vehicle under exemption age compared to neighboring incumbents that did not.

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 demonstrated 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).[4] 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 in-

[4]'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).

fant health.[5] 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 Brazil's vehicle ownership tax system, state differences in the policy, and contextualize the tax burden for an average income earner. 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. Results are presented in Section 5. Section 6 concludes.

2 Institutional Background

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

[5]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).

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.

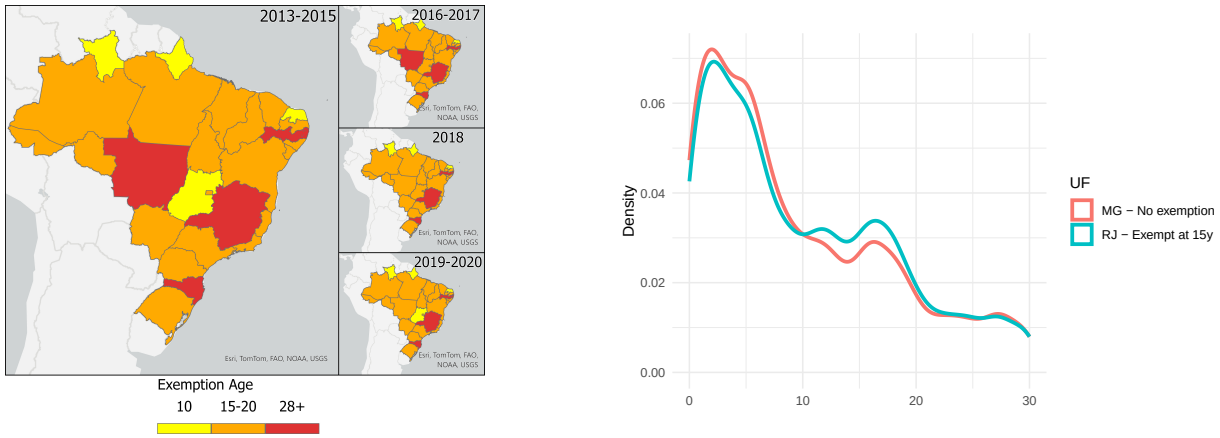
During our period of analysis five states conducted some type of change in their rules for exemption by vehicle age. In 2015, Alagoas (AL) changed their 15-year threshold into an exemption for vehicles manufactured in 2000 or earlier, and Mato Grosso do Sul (MS) raised the exemption age threshold from 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. For 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.[6] [7] If we consider the same individual owns 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.

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.

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

[7] 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.

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.[8]

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. Lastly, municipalities are assigned as part of the third layer if they not in the first or second layer but are bordering a municipality in the second layer. The remaining municipalities are not assigned to a layer and do not take part 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 in 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 for the main variables of interest comparing national average and layers 1 and 2 averages in the Appendix Table A.1. We observe that for information on vehicle fleets the national and layer level averages are qualitatively similar, however the municipalities in the layers 1 and 2 have lower levels of pollution and better

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

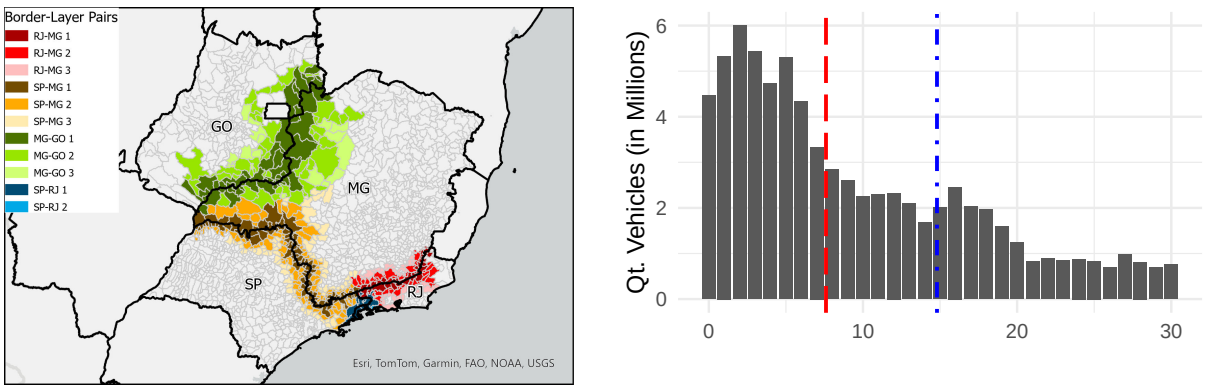
infant health outcomes.

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) Layer levels in four neighboring states

(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 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.

A shortcoming of our dataset is that we do not observe the intensity of use of vehicles. Emissions happen by the circulation of vehicles, 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.[9] 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 vehicles being scrapped informally, not notifying 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

We use satellite data of PM2.5 and carbon monoxide concentration obtained through 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 the pollutants at the municipality-year level using 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 construct average PM2.5 concentration level.[10] 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 would implicate in an attenuation bias.

[9]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 vehicles non-recovered stolen vehicles and vehicles declared as total loss after accidents.

[10]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.

To measure on-road greenhouse gas emissions, we use municipality-year estimates of GHG emissions by activity from *Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa* (SEEG) – an initiative from *Observatório do Clima*. Since we focus on vehicle emissions in this study, we use the estimates for transportation sector on-road emissions. In our main analysis we use their estimates for total on-road CO2 and NOx municipality-year emissions divided by municipality area.

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).

Because potential higher tax revenue from vehicle ownership tax in 'no-exemption' states could fund a better public health infrastructure, we control those measures in our robustness exercises. From DATASUS, we collect information on total number of hospital beds in the municipality, as well as location hospitals and other health units.

3.5 Election Data

The election process and laws in Brazil are set and supervised at the federal level, even for low administrative levels as the states. State gubernatorial elections in Brazil happen in a fixed 4-year schedule. All states vote in the same day in a first round, with a potential second round between the top two candidates happening 3 weeks later if no candidate has majority in the first round. A candidate with the majority of votes in the first (or second) round wins the election. Governors are limited to two consecutive terms, but may run again when not bounded by the consecutive limit.

We obtain electoral data from Brazil's Superior Electoral Court for gubernatorial races of 2014 and 2018, the two that happened 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. We focus our analysis on races that include a current governor, leaving us with 10 races in 2014 and 15 in 2018.

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, we obtain state-year average gasoline prices from *Agência Nacional do Petróleo* (ANP), and adjust it for inflation. 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 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.[11] 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

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

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 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 β_1 and β_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, 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 ϵ_{mt}.

The set of geographic controls include: linear distance to the border (split between higher and lower exemption age side), region fixed effects, 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 average gasoline prices, basic value-added tax rate, and presence of Interstate Highway. Environmental controls include: presence of mining site, share of municipality area impacted by fires, being part of the legal amazon, presence of fossil fuel thermal power plant, and presence of biomass power plant. Health infrastructure controls include: index for presence of health facility in the municipality, and number of beds in the public healthcare system.

We use a similar setting and specification for analyzing the political economy implications of changing the vehicle tax exemption law. Using information on first-round state gubernatorial races that include an incumbent and leveraging our border-pairs strategy, we use an econometric model with the form:

$$y_{m,t} = \alpha Increased_{S,t} + \pi Veh_{m,t} + \gamma Increased_{S,t} \times Veh_{m,t} + T'_{S,t}\psi + X'_{mt}\vartheta + \eta_{s_m - s'_n,t} + \varepsilon_{mt}. \quad (2)$$

The sets of variables $T_{S,t}$, X'_{mt} and year-border-layer pairs fixed effects are the same as the ones included in the main analysis, except that we also include a control for number of candidates in the race. The variable $Increased_{S,t}$ is a dummy that captures if the governor raised the age of tax exemption during the term (past 4 years). $Veh_{m,t}$ represents different variables we use to capture the participation of vehicle age groups in the fleet. The coefficient γ captures the differential effect of additional vehicles in that age group on the voters reaction to an increase in the exemption threshold. A municipality-election specific error term is represented by ε_{mt}. We exclude two states, and their respective border pairs from this comparison: Santa Catarina (SC) and Alagoas (AL). They are excluded because they have rules exempting vehicles produced before specific years, which could be considered as an age cutoff increase but is not attributable to changes in state laws and are expected by actors.

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.[12] An example of our identifying sample in the year 2013 is in the Appendix Figure B.1.

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 B.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.[13] For a large variety of local characteristics there are no significant differences across state borders, including VAT base rates, gasoline prices, number of public hospital beds, presence of interstate highways, GDP per capita, population, and precipitation. However, we find differences in other characteristics including presence of mining activities, power plants, and average temperature between the no-exemption and the low exemption age groups. Our main specification includes controls for all these observable local characteristics.

5 Results

In Table 1 we present the impacts of low exemption age on the 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 a average vehicle age, respectively, 1 and 0.5 years higher than municipalities across the border 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 the 10-year cutoff vehicles at 11 years and above represent 6 percentage points more of the fleet than comparable localities without exemption. Vehicles above the age of 10 years are also more prevalent (2.6 p.p.) for municipalities in the 15-20 exemption group, which is consistent with postponing scrapping decision for vehicles due to expected lower future ownership costs. We also observe that municipalities with low exemption age policies have approximately from 2.3 to 2.9 higher percentage of vehicles 21 years or older in the fleet, with the magnitude being not significantly different between the two types of low exemption policies.

[12] The combinations are border pairs with types: 10 / $15-20$, 10 / $28+$, and $15-20$ / $28+$.

[13] 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 A.1.

Even though 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 bolster 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.

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

	(1)	(2)	(3)	(4)
Panel A: Vehicle Fleet				
Dependent Variables:	Average Vehicle Age	Pct. Vehicles 11y+	Pct. Vehicles 21y+	Vehicles per capita
Exemption Age: 10	1.020***	6.376***	2.874***	0.0092
	(0.2690)	(1.303)	(0.7830)	(0.0237)
Exemption Age: 15-20	0.5655***	2.657***	2.285***	-0.0129
	(0.1699)	(0.7933)	(0.5315)	(0.0145)
Regression Statistics				
Mean Dep. Variable:	12.06 (year)	43.00 (%)	17.83 (%)	0.45
Observations	19,386	19,386	19,386	19,386
R^2	0.84852	0.82401	0.83089	0.83995
Exemption 10 = 15-20 (χ^2)	5.62**	13.73***	1.28	1.3773
Panel B: Pollutants				
Dependent Variables:	Log PM2.5	Log CO	Log CO2 (Road)	Log NOx (Road)
Exemption Age: 10	0.0414**	0.0795**	0.5086**	0.4720**
	(0.0196)	(0.0324)	(0.2146)	(0.2108)
Exemption Age: 15-20	0.0483***	0.0968***	0.2497*	0.2536
	(0.0154)	(0.0294)	(0.1449)	(0.1595)
Regression Statistics				
(Exp) Mean Dep. Variable:	7.41 ($\mu g/m^3$)	109.29 (ppbv)	30.42 (t/km^2)	0.15 (t/km^2)
Observations	19,386	19,386	18,971	18,973
R^2	0.92295	0.82811	0.83766	0.81512
Exemption 10 = 15-20 (χ^2)	0.29	1.66	2.78*	2.5518
Panel C: Infant Health				
Dependent Variables:	Average 5-min Apgar	Low Birth Weight	Very Low Birth Weight	28 Days Infant Mortality
Exemption Age: 10	-0.1860***	7.592***	2.385***	0.6089*
	(0.0496)	(1.174)	(0.3527)	(0.3577)
Exemption Age: 15-20	-0.0648**	2.883***	0.3091	0.0554
	(0.0302)	(0.9889)	(0.2164)	(0.1191)
Regression Statistics				
Mean Dep. Variable:	9.36	81.16 (per 1000)	12.79 (per 1000)	7.97 (per 1000)
Observations	19,386	19,386	19,386	19,386
R^2	0.35430	0.27006	0.14039	0.10130
Exemption 10 = 15-20 (χ^2)	10.02***	48.58***	63.933***	3.06*

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.

Given advancements in technology for fuel and emissions efficiency, as well as decreasing effectiveness of catalytic converters with use, older vehicles are, on average, more polluting than newer ones (Jacobsen et al., 2022). In Panel B of Table 1, we see that low exemption

age policies increase PM2.5 concentration by, approximately, 4.1% to 4.8%, representing an increase of $0.31\mu g/m^3$ to $0.36\mu g/m^3$. These policies are also associated with an increase of, approximately, 7.9% (9 parts per billion volume) to 9.7% (11 ppbv) in carbon monoxide concentration. Estimates of on-road emissions of greenhouse gases also point to a significant impact of exemption policies across border pairs. Municipalities with an exemption age cutoff at 10 years present CO2 and NOx emissions approximately 65% and 60% higher than neighboring municipalities across the border. Point-estimates indicate that exemption cutoff between the age of 15 and 20 are associated with approximately 28% higher on-road emissions of CO2 and NOx, however effects are not statistically significant in the case of nitrogen oxides.

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 low exemption age is associated with lower average 5-minute Apgar score, especially for the group with the cutoff at 10 years. Mothers from municipalities under a 10-year threshold policy present a 7.6 higher rate of low birth weight (under 2,500 grams) per 1,000 live births than mothers from municipalities across the border with *de facto* no exemption, with a very low birth weight rate higher by approximately 2.4 per 1,000 live births. In the case of 15-20 years cutoff, low birth weight rates surpass the baseline by approximately 2.9 per 1,000 live births, but effects are not significant for very low birth weight. We also find that the lowest exemption age group present a higher 28-day infant mortality rate, with more 0.6 infant deaths in the first 28 days after birth per 1,000.

Analyzing, in Table 2, the heterogeneous effect of low exemption age policies for relatively poorer municipalities we do not find evidence of higher "take-up" on the group. On the contrary, for the group with 15-20 year cutoff, we observe that effects for average vehicle age and percentage of vehicles above 10 and 20 years are mostly muted for municipalities below the median and at the lowest tercile of GDP per capita. However, observing the impacts for the 15-20 year cutoff group on pollutants and infant health, the policy seems to backfire: despite the apparent lower "take-up" and lower on-road emissions of CO2, the poorer municipalities still present the same elevated PM2.5 concentration and rate of low birth weight of the rest of the group, indicating potential negative spillover from in-state neighbors. On the other hand, poorer municipalities under the exemption age of 10 years do not present heterogeneous effects to the policy, with no differential impacts of fleet age distribution, pollution levels, or infant health compared to relatively wealthier localities.

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.

Table 2: Heterogeneity: GDP per capita

	Vehicle Fleet			Log Pollutant		Infant Health
Dependent Variables:	Average Age	Pct. 11y+	Pct. 21y+	PM2.5	CO2 (Road)	Low Birth Weight
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Above v. Below Median GDPpc						
Exemption Age: 10	0.8163***	5.327***	2.387***	0.0534**	0.5744**	6.415***
	(0.2800)	(1.328)	(0.8174)	(0.0242)	(0.2796)	(1.371)
Exemption Age: 10 × Below Median	0.2236	1.047	0.4724	-0.0355	-0.3330	2.235
	(0.3833)	(1.933)	(1.091)	(0.0364)	(0.3725)	(2.049)
Exemption Age: 15-20	0.7403***	3.667***	2.744***	0.0552***	0.3911***	3.144***
	(0.1632)	(0.7093)	(0.5111)	(0.0168)	(0.1361)	(0.9784)
Exemption Age: 15-20 × Below Median	-0.5766**	-3.222**	-1.546*	-0.0228	-0.4734***	-0.9813
	(0.2851)	(1.262)	(0.9146)	(0.0152)	(0.1654)	(1.333)
Regression statistics						
Observations	19,386	19,386	19,386	19,386	18,971	19,386
R^2	0.85130	0.82662	0.83396	0.92311	0.84040	0.27215
Panel B: Above v. Below Low Tercile GDPpc						
Exemption Age: 10	0.8617***	5.769***	2.355***	0.0405**	0.4343*	6.564***
	(0.2453)	(1.153)	(0.7416)	(0.0193)	(0.2203)	(1.240)
Exemption Age: 10 × Below Low Tercile	0.3101	0.9538	1.215	-0.0022	0.0629	3.003
	(0.3180)	(1.604)	(1.002)	(0.0169)	(0.4173)	(2.795)
Exemption Age: 15-20	0.6847***	3.389***	2.574***	0.0524***	0.3459***	3.161***
	(0.1551)	(0.6826)	(0.4849)	(0.0162)	(0.1284)	(0.8948)
Exemption Age: 15-20 × Below Low Tercile	-0.5642**	-3.549***	-1.331	-0.0205	-0.4777**	-1.363
	(0.2772)	(1.208)	(0.9234)	(0.0147)	(0.2243)	(1.533)
Regression statistics						
Observations	19,386	19,386	19,386	19,386	18,971	19,386
R^2	0.85438	0.82867	0.83773	0.92309	0.84158	0.27193

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.

Appendix Table C.1 show that MERRA-2 satellite-based estimates of carbon monoxide emissions are smaller but directionally in line with estimates from SEEG in the main analysis. We also show that exemption policies impact overall average birth weight, but effects are especially stronger for births from black mothers. In Appendix Table C.2 we do not find differences in vehicle fleet age composition across layer groups.

In Table 3 we observe the electoral impacts for incumbent governors that increased the age threshold for vehicle ownership tax exemption. Using data from the first round governors elections from 2014 and 2018, we observe a decrease in the municipality percentage of votes for incumbents that raised threshold. The effect is of 0.75 less percentage of votes per additional percentage of vehicle under the age of 10 years in a municipality, and of 1.39 per additional percentage of vehicle under the threshold, compared to neighboring incumbents who did raise the cutoff age. Analyzing the total of votes received by incumbents, we observe a reduction of 2% in votes on the candidate per additional percentage of vehicles under the age of 10 years, and of 3.6% per additional percentage of vehicles below the age threshold. When analyzing the impacts for each percentage of vehicles that have lost (expected) exemption status, we see obtain a non significant point-estimate of 0.66 reduction on percentage of votes for the incumbent, but with an associated 7.8 percentage reduction on votes received for the same candidate.

Table 3: Political Economy Implications of Increasing Exemption Age Threshold

Dependent Variables:	Percentage Votes on Incumbent			Log Votes on Incumbent		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Increased Threshold × Pct. Vehicles under 10y	-0.7515***			-0.0220**		
	(0.1236)			(0.0096)		
Increased Threshold × Pct. Vehicles under Threshold		-1.389***			-0.0365***	
		(0.1412)			(0.0101)	
Increased Threshold × Pct. Vehicles Lost Exemption			-0.6628			-0.0780**
			(0.6453)			(0.0358)
Fit statistics						
Observations	1,582	1,582	1,582	1,582	1,582	1,582
R^2	0.78155	0.78282	0.78113	0.68224	0.68314	0.68208

Clustered Candidate standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

The results for total votes on the governor indicate an anti-incumbent sentiment after policy change that increases with saliency of the change in exemption for voters. Owners of vehicles under the age of 10 are only directly impacted by expected increase in ownership costs for the vehicle when they would have reached exemption status or changes in expected re-sale value of the vehicle. However, owner of vehicles that already had – or where about to receive

– exemption status have a present time increase in vehicle ownership costs from this policy change, making the matter more salient to them. This is consistent with the increasing magnitude of effects for the interactions with total percentage of vehicles under threshold and for vehicles that lost exemption.

6 Concluding Remarks

Transportation is one of the main sources of greenhouse gases and pollution emissions worldwide. Although most of the regulation on vehicle emission standards are focused on new vehicles, the majority of motor vehicle pollution comes 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 relatively low exemption cutoffs from 10 to 20 years impact the fleet age distribution and can increase the average vehicle age up 1 year. Pollution levels also increase at the border in states with low exemption age. We find that local $PM_{2.5}$ concentration is raised by $0.31\mu g/m^3$ (4.1%) to $0.36\mu g/m^3$ (4.8%), on average, in low exemption municipalities close to the border. Low exemption age laws are also associated with higher carbon monoxide concentrations, as well as CO2 and nitrogen oxides emissions. Using administrative data on birth records, we also find that these policies have negative impacts on birth outcomes with a 2.9 to 7.6 increase in the rate of low birth weight per 1,000 live births.

Contrasting with the argument that these policies would be directed to increase affordability of vehicle ownership to lower income households, we do not find any impacts on the number of vehicles per capita. Relatively poorer municipalities do not present exceptional changes in fleet composition when the exemption threshold is at 10 years, but they are more similar to the fleet composition of no-exemption localities when the cutoff is between 15 and 20 years, indicating a lower "take-up" for this group. Nevertheless, poorer and wealthier municipalities have similar negative health impacts associated with these policies, regardless of potential lower "take-up" for one group, suggesting spillovers from pollution.

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 negative local and global externalities from local pollutants – impacting health in the area – and greenhouse gas emissions – contributing to climate change. 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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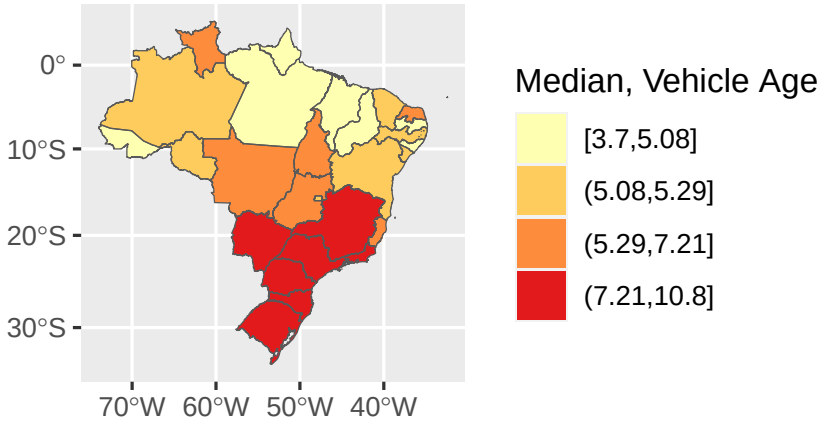
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A Data Appendix

A.1 Vehicle Data

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



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

A.2 Summary Statistics

Table A.1: Summary Statistics National vs. Layers 1-2

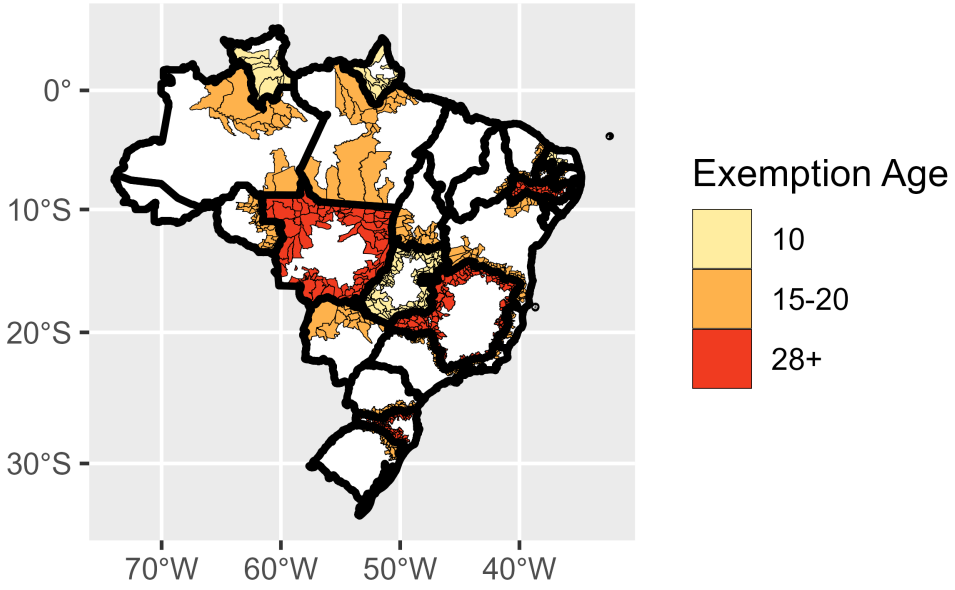
	National	Layers 1-2
Avg. Vehicle Age	12.658	12.059
	(0.600)	(0.609)
Pct. Vehicles 11+	45.383	42.991
	(2.419)	(2.344)
Pct. Vehicles 21+	20.113	17.834
	(1.905)	(1.913)
Vehicles per capita	0.497	0.447
	(0.049)	(0.038)
Log PM2.5	8.564	7.786
	(0.571)	(0.439)
Log CO	154.400	114.005
	(28.909)	(6.250)
Log CO2 (Road)	930.014	112.862
	(232.604)	(21.534)
Log NOx (Road)	4.251	0.572
	(1.115)	(0.103)
Avg. 5-minutes Apgar	9.341	9.357
	(0.040)	(0.031)
Low Birth Weight	85.659	81.150
	(1.911)	(1.833)
Very Low Birth Weight	13.878	12.784
	(0.343)	(0.381)
28-Day Infant Mortality	7.555	7.970
	(0.278)	(0.237)

Notes: Clustered State-level standard-errors in parenthesis. All regressions include 2010 municipal population weights.

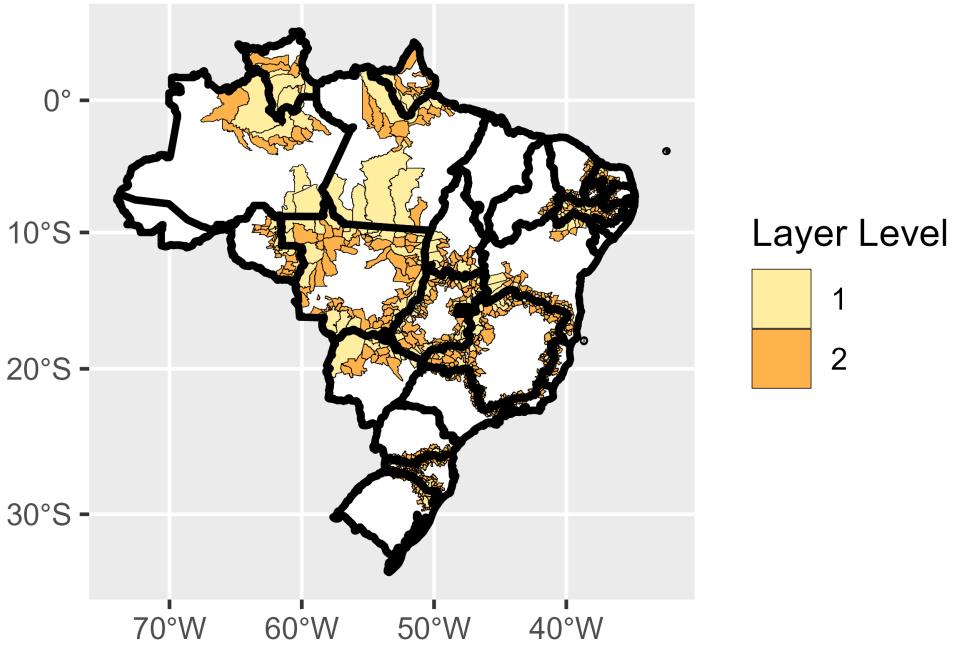
B Border-Pair Approach Appendix

B.1 Identification

Figure B.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 **??**, the identifying sample changes over time.

B.2 Characteristics across borders

Table B.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	Hospital Beds	Interstate Highway
Exemption Age: 10	0.1800	-0.0218	-0.0873**	-508.0	-0.0567
	(0.1514)	(0.0433)	(0.0413)	(307.8)	(0.0665)
Exemption Age: 15-20	0.0746	-0.0144	-0.0124	-53.11	-0.0567
	(0.1094)	(0.0362)	(0.0391)	(63.32)	(0.0454)
Regression Statistics					
Observations	19,386	19,386	19,386	19,386	19,386
R^2	0.78508	0.87636	0.13230	0.68543	0.13128
Panel B: Local Economy and Polluting activities					
Dependent Variables:	Log GDP pc	2010 Population (/1,000)	Mining Activity	Fossil Fuel Power Plant	Biomass Power Plant
Exemption Age: 10	-0.3705	-516.7	-0.2339**	-0.1824*	-0.3082**
	(0.4014)	(342.1)	(0.0950)	(0.1030)	(0.1469)
Exemption Age: 15-20	-0.0441	6.010	-0.1461***	-0.0447	-0.0942*
	(0.0767)	(29.89)	(0.0334)	(0.0333)	(0.0519)
Regression Statistics					
Observations	19,386	19,386	19,386	19,386	19,386
R^2	0.54857	0.79463	0.44453	0.38277	0.39108
Panel C: Fires, Amazon, and Weather					
Dependent Variables:	Share Fire Area	Legal Amazon	Avg. Temperature	Atmospheric Pressure	Yearly Precipitation
Exemption Age: 10	0.0064**	-0.0467	0.6711***	277.9	-9,099.4
	(0.0029)	(0.0353)	(0.1681)	(239.4)	(6,061.0)
Exemption Age: 15-20	0.0005	-0.0169*	0.4809***	412.3*	877.0
	(0.0004)	(0.0094)	(0.1680)	(222.6)	(1,444.4)
Regression Statistics					
Observations	19,386	19,386	19,386	19,386	19,386
R^2	0.55086	0.95212	0.94096	0.77257	0.58228

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.

C Results Appendix

Table C.1: Other Pollutants and Infant Health Variables

	Pollutants - MERRA-2		Avg. 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)
Variables							
Exemption Age: 10	0.0003	0.1761*	-0.0794	-23.02***	-72.01***	-18.52**	-60.24
	(0.0002)	(0.0978)	(0.0549)	(8.152)	(20.64)	(8.023)	(68.92)
Exemption Age: 15-20	0.0005***	0.2896***	-0.0413*	-7.810	-19.48**	-11.60**	-32.17
	(0.0002)	(0.0820)	(0.0234)	(4.956)	(8.124)	(4.745)	(23.69)
Regression statistics							
Observations	19,386	19,386	19,386	19,386	15,830	19,195	4,544
R^2	0.98952	0.57720	0.33643	0.46947	0.10696	0.23927	0.31384

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 C.2: Heterogeneity: Layer Groups

	Vehicle Fleet			Log Pollutant		Infant Health
Dependent Variables:	Average Age	Pct. 11y+	Pct. 21y+	PM2.5	CO2 (Road)	Low Birth Weight
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Layer 1 v. Layer 2						
Exemption Age: 10	0.9490***	6.088***	2.654***	0.0228	0.7488***	6.165***
	(0.2487)	(1.142)	(0.7587)	(0.0179)	(0.2676)	(1.249)
Exemption Age: 15-20	0.3805*	1.814**	1.870***	0.0334**	0.2190	2.182*
	(0.2006)	(0.7991)	(0.6367)	(0.0139)	(0.1586)	(1.158)
Exemption Age: 10 × Layer 2	0.2452	1.020	0.7246	0.0562**	-0.6718*	4.205**
	(0.3307)	(1.575)	(0.9828)	(0.0228)	(0.3619)	(1.930)
Exemption Age: 15-20 × Layer 2	0.4265	1.938	0.9659	0.0364***	0.0311	1.795
	(0.3240)	(1.268)	(0.9853)	(0.0106)	(0.1365)	(1.270)
Regression statistics						
Observations	19,386	19,386	19,386	19,386	18,971	19,386
R^2	0.84894	0.82455	0.83113	0.92332	0.83850	0.27035
Panel A: Layers 1-2 v. Layer 3						
Exemption Age: 10	1.052***	6.416***	3.159***	0.0532**	0.3699*	9.098***
	(0.2579)	(1.196)	(0.8639)	(0.0246)	(0.2141)	(1.160)
Exemption Age: 15-20	0.3629**	1.654**	1.695***	0.0559***	0.2320	4.098***
	(0.1564)	(0.7472)	(0.5044)	(0.0166)	(0.1484)	(0.9350)
Exemption Age: 10 × Layer 3	0.3695	1.592	0.7094	-0.0023	0.0809	-7.074**
	(0.4745)	(2.024)	(1.524)	(0.0440)	(0.2953)	(2.832)
Exemption Age: 15-20 × Layer 3	-0.4361	-1.448	-1.534	0.0522*	0.4510**	-1.374
	(0.2999)	(1.188)	(0.9356)	(0.0279)	(0.1917)	(1.244)
Regression statistics						
Observations	27,449	27,449	27,449	27,449	26,841	27,449
R^2	0.84548	0.82611	0.82376	0.92249	0.87708	0.26780

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.