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ABSTRACT

Transportation is a major source of greenhouse gas and air pollution emissions worldwide, with most automobile pollution coming from vehicles older than 10 years. Yet, many policies discourage the removal of older vehicles from the fleet, with potential consequences for pollution and public health. This paper examines an equity-motivated anti-scrappage policy in Brazil using a border-pair design that exploits state variation in the age thresholds for vehicle ownership tax exemptions. Using municipality-level vehicle registration data from 2013-2020, we find that lower exemption age thresholds increase the average fleet age by up to one year, as they encourage owners to retain vehicles until they qualify for tax exemptions. Using fleet- and satellite-based estimates of pollution and administrative health data, we show that these policies increase on-road CO2 emissions per capita by up to 23% and PM2.5 concentrations by 4%, while deteriorating infant health outcomes. Leveraging state reforms that raised exemption ages, we find evidence that incumbents face greater electoral penalties wherever a greater share of the vehicle fleet re-enters the tax base, consistent with a "political environmental trap." Within an MVPF framework, we find that lowering the exemption age by five years generates a net welfare loss of $0.78 for every $1 of forgone government revenue.

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1 Introduction

Governments frequently implement policies intended to improve equity but that distort environmental incentives. One striking example arises in the transportation sector, one of the largest sources of greenhouse gas emissions globally.[1] Although the textbook solution is a Pigouvian tax on vehicle usage, such policies are often politically unpopular and difficult to enforce—particularly in low- and middle-income countries.[2] As a result, many governments instead adopt vehicle purchase taxes, emissions standards, or registration fees that decline with vehicle age, making older vehicles relatively cheaper to operate (He and Kim, 2024).[3] These policies are typically justified on equity grounds but may backfire environmentally by extending the lifespan of disproportionately polluting vehicles (Jacobsen et al., 2023). Although politically durable and seemingly progressive, they can increase both greenhouse gas emissions and local air pollution—undermining public health and complicating efforts to decarbonize. Understanding their real-world consequences is crucial, especially as governments face growing pressure to pursue climate goals without exacerbating inequality.

We study this trade-off in Brazil, where age-based exemptions from the vehicle ownership tax create incentives to retain older, more polluting cars. Exploiting variation in exemption thresholds across states, we examine their effects on vehicle fleets, pollution, health, fiscal outcomes, and political behavior. Brazil's vehicle ownership tax (*Imposto sobre a Propriedade de Veículos Automotores*, or *IPVA*) provides a particularly useful setting for studying how tax policy affects vehicle longevity. Owners pay an annual tax based on the market value of their vehicle, but during our 2013-2020 study period, 25 of 27 states exempted vehicles once they reached a predetermined age threshold. Because older vehicles tend to be more polluting, these exemptions reduce the relative cost of keeping older vehicles on the road and weaken incentives to replace them. This design contrasts with the logic of an optimal pollution-mitigation policy, such as a Pigouvian tax, which would instead impose higher costs on more polluting vehicles to reflect their environmental externalities.

We identify the causal effects of vehicle ownership tax exemption policies by leveraging variation in exemption ages across municipalities near state borders. Building on Holmes (1998) and Kahn and Mansur (2013), we organize neighboring municipalities across state

[1] The 6th IPCC report states that the transportation sector accounts for about 15% of GHG emissions and roughly a quarter of energy-related CO_2 emissions (Jaramillo et al., 2022).

[2] Taxing vehicle air pollution emissions is not feasible because accurately measuring emissions from individual vehicles is difficult, costly, and vulnerable to manipulation or corruption (Venigalla, 2012; Oliva, 2015).

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

borders into paired groups, forming state-layer pairs. This border-pair approach allows us to compare municipalities subject to different exemption ages while holding constant many other local characteristics. The identifying assumption is that, absent differences in exemption policies, municipalities on opposite sides of a state border would have similar characteristics and outcomes. To address potential threats to this assumption, we further control for a range of geographical and local characteristics in our econometric specifications.

To operationalize the policy variation, we categorize exemption policies into three groups based on vehicle age thresholds: states with a cutoff age of 10 years, states with cutoffs between 15 and 20 years, and states with either no exemption or an exemption only for vehicles aged at least 28 years. We use the latter group as our benchmark because the small share of vehicles older than 28 years makes these policies effectively equivalent to having no exemption. Our primary comparison therefore contrasts municipalities in states with low exemption ages with municipalities in states with *de facto* no exemption policies.

Our analysis reveals that exempting vehicles above age thresholds of 10 to 20 years leads to an older fleet relative to a no-exemption policy, as owners are incentivized to retain their vehicles until they become eligible for the exemption. Using municipality-level vehicle registries from the Ministry of Transportation, we find that states with a 15-20-year exemption cutoff have average vehicle ages approximately 0.4 years higher than those in our baseline group, while states with a 10-year cutoff have average vehicle ages approximately 1 year higher. We also find evidence of bunching, with a higher share of vehicles exceeding the exemption threshold on the policy side of the border. These effects on fleet age suggest that a low *IPVA* exemption age constitutes an anti-scrappage policy.

Our findings also indicate that states with relatively low age-exemption thresholds have higher greenhouse gas emissions, greater local pollution, and worse birth outcomes, partly reflecting changes in the age distribution of the vehicle fleet. Using municipality-level, fleet-based emissions estimates from SEEG (The Greenhouse Gas Emissions and Removals Estimating System), we find that municipalities with a 10-year exemption cutoff have on-road CO_2 emissions per capita that are approximately 23% higher than the baseline, equivalent to an additional 0.23 tons per capita—roughly the annual emissions of one gasoline-powered passenger vehicle for every 20 residents.[4] Using satellite-derived pollution measures from MERRA-2, we also find that low-exemption municipalities have concentrations of fine particulate matter (PM2.5) that are approximately 4% higher and carbon monoxide concentrations that are approximately 7% higher than the baseline. Finally, using administrative

[4]The conversion from CO_2 emissions to annual passenger vehicle emissions uses the EPA's Greenhouse Gas Equivalencies Calculator and assumes average emissions of 4.29 tons of CO_2e per vehicle per year.

data from the Ministry of Health, we find that these policies are associated with worse birth outcomes, including lower average 5-minute Apgar scores (by 0.07 in the 15-20 exemption group and 0.17 in the 10-year group) and higher rates of low birth weight (by 2.3 and 8.2 per thousand live births in the 15-20 and 10-year groups, respectively).

Our results suggest that, contrary to the argument that low exemption ages facilitate vehicle ownership among lower-income families, the policy's equity benefits appear negligible. We find no evidence of higher vehicle ownership per capita under these policies, even when focusing on poorer municipalities. In contrast, in municipalities with very low exemption ages, rates of low birth weight are particularly elevated among Black mothers, a group that is typically more vulnerable, suggesting that these policies may exacerbate inequalities in health outcomes.

The widespread adoption of low exemption-age policies across Brazilian states, despite their documented negative consequences, appears to reflect local political incentives. If voters place greater weight on the private benefits of a lower expected tax burden from exemptions than on the potential public benefits of taxation, these preferences should be reflected in electoral outcomes following policy changes. Using electoral data from the Superior Electoral Court for the 2014 and 2018 gubernatorial and state assembly elections, we find suggestive evidence that politicians associated with increases in exemption-age thresholds are electorally penalized. We focus on the states of Goiás (GO) and Mato Grosso do Sul (MS), which raised exemption ages in 2015, and compare outcomes across election cycles with neighboring states that did not change policy. Our estimates indicate that, for each percentage point of the fleet share that lost exemption status, vote shares for candidates affiliated with the incumbent governor's party decline by 2.3 percentage points in gubernatorial races and 0.15 percentage points in state assembly races, relative to candidates in the comparison group. Back-of-the-envelope calculations indicate that, on average, each additional vehicle in GO and MS that lost its exemption was associated with a 1.8 vote decline for the incumbent party.

The political choices surrounding exemption thresholds carry direct fiscal implications. Leveraging policy changes in the states of GO and MS and municipality-level data from the Public Sector Accounting and Tax Information System (*SICONFI*), we find that raising exemption age thresholds by 5 years increases annual consolidated *IPVA* revenue by $35.8 BRL per vehicle. This corresponds to roughly a 1.5% increase in revenue for each percentage-point increase in the share of the fleet subject to the tax. Combining the electoral and fiscal margins reveals a sharp political-fiscal trade-off: each 1% increase in *IPVA* revenue is associated with a 1.5-percentage-point loss in vote share in the gubernatorial race.

Lastly, we quantify the welfare effects of *IPVA* exemption policies using a marginal value of public funds (MVPF), defined as the ratio of willingness-to-pay (WTP) for the policy to its net cost to the government (Finkelstein and Hendren, 2020). This framework allows us to compare the welfare effects of this anti-scrappage policy with alternative uses of public funds. Lowering the exemption threshold by 5 years generates \$1.35 BRL in private tax relief and an additional \$2.13 BRL in health-related externality costs for each \$1 BRL of foregone government revenue. Thus, accounting for both the private benefits and health costs, the net WTP is $\$1.35 - \$2.13 = -\$0.78$ BRL per \$1 BRL of forgone revenue, yielding an MVPF of approximately -0.78. This implies that generous age-based *IPVA* exemptions are lose-lose policies: fiscally costly and welfare reducing. Redirecting \$1 BRL of forgone revenue from exemptions toward electric-vehicle subsidies (Hahn et al., 2026) or state cash transfers modeled on *Bolsa Família* (Gerard et al., 2026) could instead generate as much as \$2.23 and \$3.28 BRL in welfare gains, respectively.

This paper makes three main contributions to the literature. First, it contributes to the literature on the political economy of environmental policy and the environmental consequences of non-environmental policies. Prior research has shown that political incentives shape environmental policy choices, stringency, and outcomes (List and Sturm, 2006; Stokes, 2016; Pailler, 2018; He et al., 2020; Douenne and Fabre, 2022; Dechezleprêtre et al., 2025), and that non-environmental policies and institutions can have important environmental consequences, including through trade (Shapiro, 2021) and industrial policy (Shapiro, 2025). We contribute by showing how an equity-oriented tax policy in the transportation sector—a major source of global emissions—can create an anti-environmental bias, and how its behavioral responses can generate electoral incentives that make the policy difficult to reverse, creating a "political environmental trap."[5] This highlights the political economy challenges of balancing environmental goals with fiscal and distributional concerns.

Second, it contributes to the literature on the design and implementation of policies aimed at reducing the environmental footprint of transportation. Previous work has shown that vehicle tax policy can significantly influence fleet age distribution and emissions efficiency, though often with equity implications (Jacobsen and van Benthem, 2015; Klier and Linn, 2015; Yan and Eskeland, 2018; Gillingham et al., 2022; Jacobsen et al., 2023), while other interventions—such as driving restrictions—may backfire by shifting the composition of the fleet toward higher-emitting vehicles (Davis, 2008).[6] While most of this literature focuses on developed country settings, it is unclear whether the findings apply to lower-income countries,

[5] Our results relate closely to the theoretical model of "political climate trap" (Delfgaauw and Swank, 2024).

[6] In the opposing direction, 'Cash-for-Clunkers' programs have affected fleet composition by renewing it, with positive impacts on CO_2 emissions and air quality (Li et al., 2013; Helm et al., 2023).

where corruption and limited state capacity may constrain policy effectiveness (Oliva, 2015; Jayachandran, 2022). We contribute to this literature by providing a nationwide, causal evaluation of a vehicle age-based tax exemption in a middle-income country. Our findings show that popular fiscal incentives can distort the age composition of the fleet, discourage scrappage, and ultimately undermine sustainability goals.

Third, we contribute to the literature on the health externality costs of transportation. Prior research shows that transportation-related pollution has substantial adverse effects on public health (Currie and Walker, 2011; Knittel et al., 2016; Schlenker and Walker, 2016; Alexander and Schwandt, 2022; Hansen-Lewis and Marcus, 2025).[7] Most evidence comes from developed countries, however, where effect magnitudes may differ from those in developing countries because of differences in avoidance behavior, baseline pollution levels, and healthcare infrastructure (Greenstone and Hanna, 2014; Arceo et al., 2016; Guidetti et al., 2021). We contribute by studying how a policy-induced older and dirtier vehicle fleet affects infant health outcomes in a developing-country setting, where such evidence remains scarce. We further use an MVPF framework and policy changes to quantify welfare effects, showing that transportation tax policies can trade off concentrated private benefits against diffuse health costs, with the latter outweighing the former in our setting.

This paper is structured as follows. Section 2 contextualizes Brazil's vehicle ownership tax, emissions standards, and implications to the fleet. Section 3 introduces a conceptual framework illustrating some of the mechanisms through which the vehicle tax affects fleet age, pollution, health, and the political equilibrium. Section 4 presents the data and the algorithm used to construct border-pairs. Section 5 introduces our border-pair empirical strategy. Section 6 presents the main results and a series of robustness checks. Section 7 provides evidence on the political economy and fiscal implications of this anti-scrappage policy. Section 8 offers concluding remarks.

2 Institutional Background

2.1 Brazil's Vehicle Ownership Tax (*IPVA*)

Brazil's Vehicle Ownership Tax (*IPVA*) is an annual *ad valorem* tax on motor vehicles, added to the federal Constitution in 1985 and effective from 1986, with revenue split equally between the state of registration and the municipality of the owner's residence. While the federal framework defines the object of taxation and revenue division, states set their own

[7]Related reviews summarize the broader evidence on the health and non-health effects of air pollution (Graff-Zivin and Neidell, 2013; Currie et al., 2014; Aguilar-Gomez et al., 2022).

rate schedule and rules for exemption. A vehicle owner's tax liability equals a state-set rate—typically between 1% and 4%, depending on fuel and vehicle type—applied to the vehicle's current market value, typically as listed in the *Tabela FIPE*.[8] As vehicles depreciate with age, *IPVA* liability declines mechanically as vehicles age, in contrast to the schedule of an optimal Pigouvian tax, which would increase in age to cover higher emission intensity. This comparison becomes starker in the presence of age-based exemption, which induces a sharp drop in vehicle ownership cost once the state-set age-threshold is crossed.

Although revenue generation is the main objective of the *IPVA*—generally the second-highest revenue source at the state level and accounting for 8.25% of total state tax revenues in 2020—its design, including fuel-specific rates and age-based exemptions, suggests that other policy objectives also play an important role.[9] State rate schedules also incorporate environmental considerations along the fuel-type margin. For example, the states of São Paulo and Rio de Janeiro apply lower rates to natural gas and electric vehicles than to gasoline- or diesel-powered vehicles. More recently, tax incentives for electric vehicles have been explicitly justified on environmental grounds.[10] In contrast, age-based exemptions are typically motivated by equity considerations. For instance, Constitutional Amendment 137/2025, which eliminated states' ability to tax vehicles older than 20 years, was justified by the Senate President as promoting "fiscal justice" and "eliminating a distortion that penalized the poorest families."[11]

On the household side, the annual monetary costs associated with vehicle ownership tax are also non-negligible, even for owners of older and less expensive vehicles. In 2013, considering an individual receiving the average income and owning a popular 10-year-old vehicle, a tax rate of 3% would represent around 2% of the individual's annual income, while the tax liability of a similar 15-year-old model would still account for 1.3% of their income.[12]

[8]The *Tabela FIPE*, published by the Fundação Instituto de Pesquisas Econômicas (FIPE), is a widely used reference that reports average market prices for vehicles in Brazil and serves as the standard benchmark for valuation in taxes and insurance.

[9]States in Brazil rely on three main taxes, in order of typical revenue relevance: (i) Goods and Services Value-added Tax (*ICMS*), (ii) Vehicle Ownership Tax (*IPVA*), and (iii) Donation and Inheritance Transfer Tax (*ITCD*).

[10]See https://www.estadao.com.br/economia/guerra-fiscal-ipva-estados-veiculos-hibridos-eletricos/.

[11]See https://www12.senado.leg.br/noticias/materias/2025/12/09/promulgada-emenda-que-isenta-ipva-de-veiculos-com-mais-de-20-anos.

[12]We obtain the monthly average usual income from Brazil's Continuous National Household 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. We also 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.

The *IPVA* age-based exemption is the most consequential design choice for our analysis. 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), focusing on 2013, we see that 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, and the remaining majority held cutoffs between 15 and 20 years.

During our period of analysis, six states modified their rules governing age-based vehicle tax exemptions. In 2015, Alagoas replaced its 15-year threshold with an exemption for vehicles manufactured in 2000 or earlier; Tocantins eliminated its 15-year age-based exemption; and Mato Grosso do Sul increased its exemption threshold from 15 to 20 years. In 2018, Santa Catarina revised its rule from exempting vehicles manufactured in 1985 or earlier to exempting vehicles older than 30 years. Mato Grosso introduced an 18-year age threshold, replacing a previous policy that did not condition exemptions on vehicle age. Goiás followed a non-monotonic pattern, raising its exemption threshold from 10 to 15 years in 2015 and then lowering it back to 10 years in 2018. All changes to the vehicle ownership tax take effect in the year following their enactment.

The presence of an age-based tax exemption creates an incentive to retain older vehicles in the fleet. Vehicles above the cutoff age face lower present ownership costs than they would in the absence of such exemptions. However, vehicle ownership decisions are inherently dynamic: expectations of future reductions in tax liabilities also influence behavior before the exemption is actually realized. As a result, even vehicles below the exemption threshold may have lower expected lifetime ownership costs when they are closer to the cutoff age, compared to newer vehicles, due to the anticipated future tax relief.

To illustrate these potential effects, Figure 1, Panel (b), presents the vehicle age distribution in two neighboring states, Rio de Janeiro (RJ) and Minas Gerais (MG). Minas Gerais does not have an age-based exemption, whereas in Rio de Janeiro vehicles are exempt after 15 years. The two distributions follow a similar pattern up to approximately 10 years of age, although Minas Gerais exhibits a higher density of vehicles in this range. Between 10 and 15 years, however, a divergence emerges, with Rio de Janeiro showing a progressively higher vehicle density. After the exemption threshold, this gap narrows, and the distributions converge for vehicles older than 20 years.

2.2 Emissions: Standards and Deterioration

Extending vehicle lifespan leads to higher average fleet emissions. This effect arises from two main channels: first, regulatory-driven technological improvements reduce the emissions of newer vehicles over time; and second, for a given vehicle model, emission rates tend to increase with age due to the deterioration of emission control systems.[13]

Brazil's regulatory efforts to limit motor vehicle emissions start with the creation of the Vehicle Air Pollution Control Program (*PROCONVE*) in 1986.[14] The program then lays out a schedule of successive phases that gradually tighten emission limits for different types of vehicles, initially focusing on carbon monoxide (CO), total hydrocarbons (HC), and nitrogen oxides (NO_x). Appendix Table A.1 presents the historical PROCONVE phases for gasoline-powered light-duty (L-standards) and diesel-powered heavy-duty (P-standards) vehicles. The reductions in emission standards are striking. Taking gasoline-powered light-duty vehicles (LDV) as an example, CO emission limits declined from $24g/km$ in phase L1 (1989–1991) to $1.3g/km$ in phase L6 (2014–2021), a reduction of about 95%.

Progressively stricter emission standards have led to corresponding declines in the emission rates of new vehicles. Using calculations from CETESB (São Paulo State Environmental Protection Agency) on average emission rates of new gasoline-powered LDVs from 1985 to 2020, we plot in Appendix Figure A.1 the reductions in CO and NO_x emission rates—regulated under PROCONVE—as well as CO_2 emissions starting in 2002.[15] Over the period, average CO and NO_x emission rates for new vehicles in this category declined by approximately 99%. From 2002 to 2020, average CO_2 emissions—which are not regulated under PROCONVE standards—fell by about 25%.[16]

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

[13] Jacobsen et al. (2023) documents these two patterns in the U.S. vehicle fleet under existing regulatory conditions.

[14] The program is created via the *CONAMA* (Brazil's National Council for the Environment) Resolution 18 of May 6, 1986: https://conama.mma.gov.br/?option=com_sisconama&task=arquivo.download&id=41.

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

[16] CO_2 emissions are typically addressed through fuel economy standards. In 2009, Brazil introduced a (primarily) voluntary Vehicle Labeling Program (PBEV) to promote energy efficiency. Participation in this program became mandatory under the *Rota 2030* Program (Law 13,755 of December 10, 2018), which also set a target of an 11% reduction in fuel consumption for the fleet of new vehicles by 2022.

same fleet exhibits substantially higher emissions, averaging $0.57g/km$ of CO and $0.07g/km$ of NO_x.

With progressively lower emission rates from new vehicles, and assuming that emissions from manufacturing new vehicles are not too large, accelerating fleet renewal through vehicle fees can increase welfare (Jacobsen et al., 2023).[17] However, Brazil's vehicle ownership tax is structured in the opposite direction: fees decline with vehicle age and fall to zero after the exemption threshold, while the environmental externality costs of vehicle use increase with age. By lowering the relative cost of owning older vehicles compared to newer ones, this policy creates incentives to retain older, more polluting vehicles in the fleet, thereby increasing the average emissions of both local and global pollutants.

3 Conceptual Framework

This section develops a simple framework to illustrate the links between vehicle ownership decisions, societal outcomes—including air pollution, public health, and public good provision through tax revenue—and the resulting political equilibrium that determines the tax exemption threshold. It highlights three core mechanisms that guide our empirical analysis and interpretation of the findings. First, tax policy affects households' dynamic replacement decisions, shaping the distribution of vehicle ages. Second, forward-looking (anticipatory) behavior and idiosyncratic shocks smooth replacement choices but generate excess mass around policy discontinuities. Third, the induced distribution feeds back into policy through environmental externalities, health impacts, and government budget considerations.

3.1 Household Behavior

Time is discrete, and a continuum of households each owns a vehicle with age $a \in \mathbb{N}$. In every period, a household decides whether to keep its current vehicle or replace it. Replacing requires paying a fixed cost K and resets the vehicle age to zero. The per-period utility from keeping a vehicle of age a is

$$u(a, \varepsilon_a) = -c(a) - T(a; \bar{a}) + \varepsilon_a^k,$$

[17] Jacobsen et al. (2023) provide evidence of the higher environmental externalities of older vehicles compared to the environmental costs of the manufacturing of a new vehicle. Using data from the 2000 US fleet and manufacturing supply chain, they estimate air pollution environmental costs of producing a new vehicle at about $600 USD. In comparison, vehicles manufactured in that same year would have annual pollution costs surpassing the $600 USD benchmark from the age of 6 years onward, and remarkably doubling this annual cost by the age of 16 years.

where $c(a)$ denotes increasing operating costs, $T(a;\bar{a})$ is the tax schedule, and ε_a^k is an i.i.d. idiosyncratic shock.

The tax system features an exemption threshold $\bar{a}$:

$$T(a;\bar{a}) = \begin{cases} \tau V(a) & \text{if } a \leq \bar{a}, \\ 0 & \text{if } a > \bar{a}, \end{cases}$$

with vehicle price $V(a)$ decreasing in age. A lower $\bar{a}$ corresponds to a more generous exemption policy. The discrete drop in taxes at $\bar{a}$ creates a dynamic incentive to delay replacement.

Households are forward-looking and form expectations of future ownership and replacement costs given the tax policy in place. Let $W(a;\bar{a})$ denote the value function. The Bellman equation is

$$W(a;\bar{a}) = \mathbb{E}_\varepsilon \left[\max \left\{ -c(a) - T(a;\bar{a}) + \varepsilon_a^k + \beta W(a+1;\bar{a}),\ -K + \varepsilon_a^r + \beta W(0;\bar{a}) \right\} \right].$$

where K is a fixed cost of replacing the vehicle and ε_a^r is an i.i.d. shock to replacement costs.

This dynamic discrete choice structure implies the replacement probability:

$$p(a;\bar{a}) = P\big(\varepsilon_a^k - \varepsilon_a^r < \underbrace{(-K + \beta W(0;\bar{a}))}_{v_r} - \underbrace{(-c(a) - T(a;\bar{a}) + \beta W(a+1;\bar{a}))}_{v_k(a)}\big).$$

Generally, the replacement probability increases with vehicle age as the increase in operating costs dominates the lowering of taxes from vehicle devaluation. However, the discrete drop in taxes at the threshold $\bar{a}$ impacts the replacement decision in two ways: (i) for owners of vehicles above the threshold, it decreases the contemporaneous cost of ownership; and (ii) owners of taxed vehicles have an incentive to delay replacement in anticipation of lower ownership costs through the continuation value. Moreover, this anticipatory incentive is larger in value the closer one is to reaching exemption status.

3.2 Stationary Distribution of Vehicle Age

The replacement behavior of households determines the long-run distribution of vehicle ages. The stationary density function $f(a;\bar{a})$ is governed by

$$\begin{aligned} f(a+1;\bar{a}) &= (1 - p(a;\bar{a}))f(a;\bar{a}), \\ f(0;\bar{a}) &= \sum_a p(a;\bar{a})f(a;\bar{a}). \end{aligned}$$

In the presence of low exemption thresholds, the distribution is shifted towards older vehicles relative to a no-exemption policy ($\bar{a} = \infty$). With a finite threshold, the discrete drop in $T(a; \bar{a})$ leads directly to a lower probability of replacement at and just above $\bar{a}$, inducing bunching above the threshold. However, anticipation also distorts behavior before reaching $\bar{a}$, potentially generating excess mass just before the threshold. Thus, an accumulation of older vehicles arises endogenously from forward-looking behavior and differences in ownership costs.[18]

3.3 Downstream Effects: Pollution, Health, and Tax Revenue

Vehicle age determines emissions, with $e(a)$ increasing in a. Aggregate emissions are

$$E(\bar{a}) = \sum_{a} e(a) f(a; \bar{a}),$$

and pollution is given by

$$P(\bar{a}) = \phi E(\bar{a}) + \eta.$$

Pollution affects health outcomes according to

$$H(\bar{a}) = H_0 - \xi P(\bar{a}).$$

More generous exemptions (lower $\bar{a}$) shift the distribution toward older vehicles, increasing emissions, worsening pollution, and reducing health.

The government collects tax revenues

$$R(\bar{a}) = \sum_{a \leq \bar{a}} \tau V(a) f(a; \bar{a}),$$

which finance a public good $G(\bar{a}) = R(\bar{a})$.

3.4 Equilibrium Policy

Equilibrium policies reflect the households' preferences. Individuals care about private taxes, health, and public goods. The indirect utility of an individual with vehicle age a_i is

$$U_i(a_i; \bar{a}) = -T(a_i; \bar{a}) + \kappa H(\bar{a}) + \gamma G(\bar{a}),$$

[18] We further detail the household behavior model under additional hypotheses and its implications for the fleet age distribution in the Appendix B.

where κ captures the marginal utility of health quality, and γ the value of public spending.

Policy is determined by majority voting. A marginal decrease in $\bar{a}$ (a more generous exemption, $\partial g = -\partial \bar{a}$) reduces tax liabilities for individuals near the threshold ($\frac{\partial T}{\partial g} = -\frac{\partial T}{\partial \bar{a}} \leq 0$), deteriorates health quality ($\frac{\partial H}{\partial g} = -\frac{\partial H}{\partial \bar{a}} \leq 0$) via the pollution channel, and reduces public revenues ($\frac{\partial R}{\partial g} = -\frac{\partial R}{\partial \bar{a}} \leq 0$). The equilibrium threshold $\bar{a}^{PE}$ satisfies

$$\tau V(\bar{a}^{PE}) f(\bar{a}^{PE}; \bar{a}^{PE}) = \kappa \frac{dH(\bar{a}^{PE})}{d\bar{a}} + \gamma \frac{dR(\bar{a}^{PE})}{d\bar{a}}.$$

The left-hand side captures the marginal private benefit of expanding the exemption, while the right-hand side reflects the marginal social costs through negative health externalities (induced by pollution) and reduced public good provision. The key insight is that the exemption policy not only distorts individual behavior but also reshapes the political landscape. By inducing bunching at the threshold, it increases the mass of individuals who benefit from marginal policy changes, thereby amplifying political pressure in favor of more generous exemptions (that is, lower exemption thresholds). When concerns about health and environmental quality are weak (low κ), the equilibrium places disproportionate weight on private tax relief, leading to exemption thresholds below the socially optimal level.

3.5 Marginal Value of Public Funds

This framework maps naturally into a marginal value of public funds (MVPF) object. Consider a marginal decrease in $\bar{a}$, which corresponds to a more generous exemption policy, and define $g = -\bar{a}$. The MVPF is the ratio of aggregate willingness to pay (WTP) for the policy to its net fiscal cost (Finkelstein and Hendren, 2020):

$$\text{MVPF}(\bar{a}) = \frac{dWTP(\bar{a})/dg}{-dR(\bar{a})/dg}.$$

Because aggregate welfare includes the value of public goods financed by tax revenue, $W(\bar{a}) = WTP(\bar{a}) + \gamma R(\bar{a})$, so

$$\text{MVPF}(\bar{a}) = \frac{dW(\bar{a})/dg - \gamma\, dR(\bar{a})/dg}{-dR(\bar{a})/dg} = -\frac{dW(\bar{a})/d\bar{a}}{dR(\bar{a})/d\bar{a}} + \gamma.$$

A marginal change in $\bar{a}$ affects welfare through three channels: private tax payments, health

(via pollution), and public goods ($G(\bar{a}) = R(\bar{a})$):

$$\frac{dW(\bar{a})}{d\bar{a}} = -\int \frac{\partial T(a;\bar{a})}{\partial \bar{a}} f(a;\bar{a})\, da + \kappa \frac{dH(\bar{a})}{d\bar{a}} + \gamma \frac{dR(\bar{a})}{d\bar{a}}.$$

The discontinuity in the tax schedule implies that only agents at the threshold are directly affected by a marginal change in $\bar{a}$. Using $T(a;\bar{a}) = \tau V(a)\mathbf{1}\{a < \bar{a}\}$, we obtain

$$\int \frac{\partial T(a;\bar{a})}{\partial \bar{a}} f(a;\bar{a})\, da = \tau V(\bar{a})\, f(\bar{a};\bar{a}).$$

Thus, the marginal willingness to pay for a change in the threshold is governed by the mass of vehicles at the cutoff.

Similarly, the marginal change in revenue can be decomposed as

$$\frac{dR(\bar{a})}{d\bar{a}} = \tau V(\bar{a})\, f(\bar{a};\bar{a}) + \frac{dR^{\text{beh}}(\bar{a})}{d\bar{a}} = \tau V(\bar{a}) f(\bar{a};\bar{a}) + \int_{a \le \bar{a}} \tau V(a) \frac{\partial f(a;\bar{a})}{\partial \bar{a}}\, da,$$

where the first term captures the *mechanical* effect and the second term reflects *behavioral* responses through changes in the stationary distribution. The mechanical effect captures the additional revenue generated, holding the stationary distribution fixed, when an increase in the exemption threshold makes vehicles at the margin newly taxable; equivalently, lowering the threshold reduces revenue by the tax liability of vehicles at the margin. The behavioral effect captures the additional change in revenue arising from adjustments in households' replacement decisions and, consequently, the stationary distribution of vehicle ages.

Combining these expressions yields a simple representation of the MVPF of a more generous exemption policy (lowering $\bar{a}$):

$$\text{MVPF}(\bar{a}) = \frac{\tau V(\bar{a}) f(\bar{a};\bar{a}) - \kappa \frac{dH(\bar{a})}{d\bar{a}} - \gamma \frac{dR(\bar{a})}{d\bar{a}}}{\frac{dR(\bar{a})}{d\bar{a}}} + \gamma.$$

Equivalently,

$$\text{MVPF}(\bar{a}) = \underbrace{\frac{\tau V(\bar{a}) f(\bar{a};\bar{a})}{dR(\bar{a})/d\bar{a}}}_{\text{marginal beneficiaries}} - \underbrace{\kappa \frac{dH(\bar{a})/d\bar{a}}{dR(\bar{a})/d\bar{a}}}_{\text{external costs}}. \tag{1}$$

This expression highlights four sufficient statistics for welfare analysis: (i) the value of vehicles at the margin of exemption, which governs the magnitude of tax relief for affected beneficiaries; (ii) the mass of vehicles at the exemption threshold, which determines the

extensive margin of beneficiaries and is amplified by bunching; (iii) the responsiveness of health-related costs to the policy; and (iv) the fiscal response of revenues. An MVPF above one indicates that the aggregate willingness to pay for expanding the exemption, net of the associated health costs, exceeds its fiscal cost.

In the empirical analysis, we combine the observed distribution of vehicle ages with our estimates of behavioral, health, and fiscal responses to quantify these sufficient statistics and, in turn, evaluate the MVPF of a change in the exemption policy.

4 Data

This section provides a brief description of the data sources and the construction of the main variables used in our study.[19]

4.1 Borders and Layers

In the main analysis, we rely on border-pairs, which are groups of geographically matched municipalities located near state borders. We construct them in three steps: (i) assigning municipalities to border-layer levels, (ii) matching municipalities to their closest out-of-state neighbor within the same layer level, and (iii) grouping municipalities of same layer level that are matched to the same neighboring state.

The assignment of municipalities to layer levels follows a recursive algorithm. In Figure 2, Panel (a), we illustrate an example of layer groups across neighboring states. Municipalities at a state's border are assigned to the first layer, while non-border municipalities that touch at least one first-layer municipality are assigned to the second-layer. Our main analysis focuses on municipalities in layer-levels 1 and 2; however, our political and fiscal exercises include a third layer—built recursively following the same procedure—for increased power. Municipalities that do not fall into any of these layers are excluded from our analyses.

In the second step, we match each municipality to its closest out-of-state neighbor within the same layer level. To do so, we compute the linear distances between the centroids of all municipality pairs and identify the closest municipality in a different state and at the same layer level. This procedure defines a pair for each municipality.[20]

In the third and final step, we assign municipalities into groups based on these pairings.

[19] Summary statistics are reported in Appendix Table C.2; however, all regression tables report the mean of the dependent variable for reference.

[20] Each municipality is assigned a single pair, but a given municipality can be the pair to many.

Specifically, we group municipalities within a given state-layer that are matched to the same neighboring state. This yields a state-border layer. Overall, this procedure generates 98 state-borders. An example of paired border-layers surrounding the state of Minas Gerais (MG)—five of them—is presented in Figure 2, Panel (a).

4.2 Vehicle Data

Our vehicle data are derived from a public municipality-level aggregation of Brazil's National Registry of Motor Vehicles (*RENAVAM*). Vehicle records are collected by each state's Department of Transit following a national guideline, and agencies are supervised by the Ministry of Transport to guarantee consistency in practices. The registration follows the owner's municipality of residence, and local governments have an incentive to monitor compliance, through sharing of tax revenue. Although the registry's data lack information on vehicle circulation, the commonality of rules and practices across states together with our border-pair research design minimizes the influence of this limitation in our analysis. More institutional information on *RENAVAM* is provided in Appendix C.

For each municipality-year, from 2013 to 2020, we observe the number of registered vehicles by vintage, allowing us to recover the age distribution of the registered fleet. In Figure 2, Panel (b), we show the national age distribution in 2013. The majority of vehicles are under 10 years old, with a median age of 7.6 years; but a substantial share is located between 10 and 20 years old—the usual range in which exemption thresholds are set. Less than 10% of vehicles are older than 28 years, implying that only a small fraction would be contemporaneously affected by states adopting exemption cutoffs at or above this level.

4.3 Pollution Data

To measure on-road emissions, we use municipality-year estimates of pollution emissions by activity from the *Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa* (SEEG)—an initiative of the *Observatório do Clima* (De Azevedo et al., 2018). SEEG's methodology follows the IPCC guidelines and Brazil's National Inventory of Greenhouse Gas Emissions and Removals.[21] In our main analysis, we use their municipality-year estimates of CO_2 and NO_x emissions from road transport.

We complement that with satellite-based measurements of $PM_{2.5}$ and carbon monoxide concentrations from MERRA-2 (Gelaro et al., 2017).[22] We aggregate the monthly gridded data

[21] On-road emissions are estimated using a bottom-up fleet-based approach that accounts for fleet composition, usage, and emission efficiency.

[22] Estimates of PM2.5 from Van Donkelaar et al. (2021) were also considered but found less suitable for our

($0.5° \times 0.625°$) to the municipality-year level according to area-weighted averages.[23] Using satellite-level data provides the advantage of observing pollution levels consistently across the country. However, a limitation is that remote-sensing pollution data might exhibit a downward bias at higher levels of pollution (Fowlie et al., 2019), which would imply an attenuation bias within our research context.

4.4 Health Data

We use administrative health data from the Brazilian Unified Health System Database (DATASUS). We collect birth and death records that include information on Apgar score, birth weight, and age at the time of death. From these data, we construct indicators for low birth weight (less than 2,500 grams), very low birth weight (less than 1,500 grams), and death within 28 days of birth, which accounts for the majority of infant mortality. We aggregate these measures at the municipality-year level. We also obtain, from DATASUS, information on the total number of hospital beds in each municipality and the location of health units, which we use as control variables in our main analysis.

4.5 Election Data

We obtain electoral data from Brazil's Superior Electoral Court for gubernatorial and state assembly elections held in 2014 and 2018, the two state election cycles that fall within our period of analysis. Brazilian state elections are held on a fixed four-year cycle, coinciding with presidential elections. The dataset includes municipality-level vote counts for each candidate. For comparability, we restrict attention to first-round elections.[24]

Our main variables are the municipality-level vote share of each candidate, the number of candidates in each race, candidate party affiliation, and an indicator for whether the candidate belongs to the same party as the incumbent governor. Our analysis focuses on elections in the subset of states that experienced changes in exemption thresholds, as detailed in Section 7. While the main analysis focuses on the first two border layers, we expand the sample to three layers in the electoral and fiscal analyses to increase statistical power given the limited number of available comparisons.

context. We further detail the comparison between MERRA-2 and Van Donkelaar in Appendix C.

[23] We follow the MERRA-2 documentation to derive PM2.5 from column mass densities of five aerosols: black carbon, dust, sea salt, organic carbon, and sulfate.

[24] Second rounds occur only when no candidate secures a simple majority in the first round and apply only to executive-branch races.

4.6 *IPVA* Tax Revenue and Healthcare Expenditures

We gather data on municipal *IPVA* revenue and public healthcare expenditures from the Brazilian Public Sector Accounting and Tax Information System (SICONFI). Our analysis focuses on municipal *IPVA* revenue per vehicle—the tax object—and municipal healthcare expenditures per capita. For the fiscal and healthcare spending analysis, our sample again consists of the subset of states that experienced changes in exemption thresholds, expanded to include three border layers to increase statistical power, as detailed in Section 7.

4.7 Additional Data

We collect data on a wide range of control variables. For brevity, we refer to these variables and data sources within thematic groups in this section, and leave more detailed explanations to Appendix C. Weather variables are obtained from Saldanha et al. (2024) based on ERA5-Land data (Hersbach et al., 2020). Value added tax (*ICMS*) and fuel prices data are collected from state legislative texts and from a dataset by *Agência Nacional do Petróleo* (ANP). Data on sources of polluting activities are drawn from *MapBiomas* (Souza et al., 2020). Information on municipality population, GDP, and highway presence are obtained from the Brazilian Institute of Geography and Statistics (*IBGE*) by means of *Base dos Dados* and *IPEADATA*, and from the World Bank's data catalog.

5 Border-Pair Approach

In our empirical analysis, our goal is to capture the effect of different exemption age thresholds for the vehicle ownership tax (*IPVA*) on local fleet age and a series of downstream outcomes. Since this policy is set at the state level, we leverage the discrete change in treatment at the border among close municipalities. Explicitly, we implement a border-pair approach building on Holmes (1998) and Kahn and Mansur (2013).

In an ideal experiment, exemption policies would be randomly assigned across municipalities, ensuring that, on average, municipalities facing different exemption thresholds would be similar in all baseline characteristics. In this setting, differences in average outcomes across groups of municipalities could be attributed to the effects of the different exemption policies.

The border-pair approach approximates the thought experiment by restricting the analysis to geographically close groups of municipalities located on opposite sides of a state border, under the assumption that assignment to either side is "as good as random." Pairing nearby municipalities helps ensure that they are similar, on average, in both observable and un-

observable characteristics. Because state borders may be shaped by underlying geographic differences—for example, a river or mountain separating two states—our main specification controls for a rich set of observable characteristics, including other potentially confounding policy differences. Our identification therefore rests on the assumption that, conditional on these observable differences, paired groups of municipalities represent each other's counterfactual under the alternative policy.

Explicitly, consider municipalities (m, n) in states (S, S') that belong to the same border-pair $S - S'$. Our identifying assumption is that, conditional on having the same observable characteristics ($X_m = x$ and $X_n = x$), municipalities exposed to the same policy τ would be expected to have the same outcome:

$$E[\ y_m(\tau) \mid X_m = x,\ m \in S] = E[\ y_n(\tau) \mid X_n = x,\ n \in S']\ ,\ \text{for}\ (m, n) \in S - S'.$$

In this way, the impact—in terms of an outcome y—of having adopted a policy τ' instead of τ can be captured by the difference:

$$\begin{aligned}\beta(\tau', \tau) &= E[\ y_m(\tau') \mid X_m = x,\ m \in S] - E[\ y_m(\tau) \mid X_m = x,\ m \in S] \\ &= E[\ y_m(\tau') \mid X_m = x,\ m \in S] - E[\ y_n(\tau) \mid X_n = x,\ n \in S'],\ \text{for}\ (m, n) \in S - S'.\end{aligned}$$

5.1 Paired Border-Layers

The pairing of close groups of municipalities across the state borders is crucial for our identification strategy. The construction of the border-layer pairs was described in Section 4. The effects of age exemption from *IPVA* are identified by the variation in implemented policies within border-layer pairs. We categorize exemption policies into three groups: exemption at 10 years, exemption age cutoff between 15 and 20 years, and exemption at 28 years or older. The last group is considered as a *de facto* no-exemption policy, due to the relatively small number of vehicles reaching ages above 28. We exploit within-pair differences in policies across all possible combinations.[25]

By limiting our analysis to municipalities close to the border, we intend to minimize potential differences in observable and non-observable characteristics between the groups, in absence of the policy differences. Under the hypothesis that closer municipalities are better counterfactuals than ones farther apart, there is an inherent bias-variance trade-off when choosing the maximum level of layers to be analyzed. We opt to include, in our main analysis, the

[25] An illustration of the sample used to identify the effects of exemption policies in 2013 is provided in Appendix Figure D.1.

first and second layers of municipalities from the border as a form of balancing the benefits of higher statistical power and confidence in the comparability of the groups. Heterogeneity analysis by layer levels is included in the Online Appendix.

Moreover, to verify the similarity of our groups of comparison, in Appendix Table D.1 we construct a balancing check of a series of characteristics across paired groups of municipalities across state borders with differing exemption policies. Holding fixed the paired groups of border-layers and locational characteristics, we see that 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 healthcare facilities, presence of interstate highways and fossil fuel power plants, log GDP per capita, population, area, and precipitation.[26] However, we find differences in other characteristics including distance to the closest border, presence of mining activities and healthcare 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.

To illustrate the approach, Figure 2, Panel (a), presents all border-layer pairs relevant to the state of Minas Gerais (MG), which follows a *de facto* no-exemption policy. All neighboring states of MG adopt lower exemption thresholds. For example, in 2013 Goiás (GO) applied an exemption cutoff age of 10 years. By comparing municipalities within the same layer pair and controlling for observable characteristics, the paired groups *MG-GO1* and *MG-GO2*—corresponding to first- and second-layer pairs—allow us to estimate the effect of a 10-year exemption policy relative to a no-exemption regime. This is achieved by using municipalities in MG as counterfactuals for neighboring municipalities in GO. Our regression analysis performs all feasible within-border-pair comparisons across the country at each point in time and then aggregates these within-border-pair differences.

5.2 Implementing the Empirical Strategy

Using the sample of paired groups of municipalities in layers 1 and 2, we estimate the following equation:

$$\begin{aligned} y_{m,t} = \beta_{10}\mathbf{1}\{Exempt\ 10\}_{S,t} + \beta_{15-20}\mathbf{1}\{Exempt\ 15-20\}_{S,t} \\ + T'_{S,t}\delta + X'_{m,t}\theta + \mu_{S_m - S'_n(l),t} + \epsilon_{m,t}. \end{aligned} \tag{2}$$

The variables $1\{Exempt\ 10\}_{S,t}$ and $1\{Exempt\ 15-20\}_{S,t}$ are dummies equal to 1 if, at year t, the exemption age threshold faced by municipality m in state S is at 10 years or between

[26] Locational controls are region dummies and latitude-longitude quadratic polynomials.

15 and 20 years, respectively. The category for municipalities with exemption age threshold above 28 years is omitted, such that the parameters β_{10} and β_{15-20} capture the comparison to this baseline category. The vector $T_{S,t}$ measures the vehicle ownership tax rate, at each state and year, for different types of vehicles: gasoline cars, ethanol cars, trucks, and motorcycles. We use the vector of variables $X'_{m,t}$ to represent our set of additional controls that can be categorized as geographic, economic and policy, environmental, and healthcare variables. The border-layer pair is introduced by the set of fixed-effects $\mu_{S_m - S'_n(l),t}$, that captures the pairs of border-layers between neighboring states (S_m and S'_n, with layer level l) at each year t—as a visual example, each group of municipalities assigned to the same color and tone in Figure 2 is symbolized each year by a separate fixed-effect. A municipality-year specific error term is represented by $\epsilon_{m,t}$.

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

To account for any potential correlation across same-state municipalities within a border-pair, we cluster the standard errors at the state-border level—the group of same-state municipalities paired to a same neighboring state, regardless of layer level. Using Figure 2 for reference, within each state, all municipalities represented by both darker (layer 1) and lighter (layer 2) tones of a color are grouped into the same state-border cluster.

Heterogeneity: To assess the potential equity implications of the policy, we also test whether relatively poor municipalities have differential effects of low-age exemptions on the outcome variables. For this analysis, we define the municipalities in the bottom tercile of the distribution of the GDP per capita between 2002 and 2010 as the relatively 'poor' group and hold the remaining municipalities as the 'non-poor' group of comparison. We implement

this by estimating the following equation:

$$
\begin{aligned}
y_{m,t} = {} & \beta_{10}\mathbf{1}\{Exempt\ 10\}_{S,t} + \beta_{15-20}\mathbf{1}\{Exempt\ 15-20\}_{S,t} + \tau Poor_m + \\
& \lambda_{10}\mathbf{1}\{Exempt\ 10\}_{S,t} \times Poor_m + \lambda_{15-20}\mathbf{1}\{Exempt\ 15-20\}_{S,t} \times Poor_m + \\
& T'_{S,t}\delta + X'_{m,t}\theta + \mu_{S_m - S'_n(l),t} + \xi_{m,t}.
\end{aligned} \tag{3}
$$

The variable $Poor_m$ indicates whether the municipality stands in the bottom third of the GDP per capita distribution. Under this specification, the parameters β_{10} and β_{15-20} capture the average outcome differences between each low-age exemption policy group and the *de facto* no-exemption group among the 'non-poor' municipalities. The analogous differences for the 'poor' municipalities are captured by the sums $\beta_{10}+\lambda_{10}$ and $\beta_{15-20}+\lambda_{15-20}$, respectively.

6 Main Results

6.1 Impacts of Exemptions on Vehicle Fleet, Pollution, and Health

Table 1 reports the estimated effects of lower exemption age thresholds on vehicle fleet, pollution, and infant health outcomes, relative to a *de facto* no-exemption policy. Panel A shows that municipalities near state borders subject to a 10-year exemption threshold and those in the 15- to 20-year cutoff group have average vehicle fleets that are 1 and 0.43 years older, respectively, than comparable municipalities without age-based exemption policies. The higher average fleet age in these localities is also reflected in a larger share of vehicles above the exemption age. In localities with a 10-year cutoff, vehicles at least 11 and 21 years old account for 6.19 and 2.77 percentage points more of the fleet, respectively, than in comparable municipalities without an exemption policy. We also find higher shares of older vehicles in localities in the 15- to 20-year threshold group, although the differences are smaller in magnitude. Because the exemption benefit is realized later under higher age thresholds, the present value incentive to retain an older vehicle is weaker, which may explain the smaller effects for the 15- to 20-year group.

Although low-exemption-age policies are often justified on the grounds that they make vehicle ownership more affordable for lower-income households, we find no evidence that they increase vehicle ownership. The number of vehicles per capita does not change significantly across borders with different exemption policies. One possible explanation is that the expected tax savings are largely non-binding for households' decisions to acquire vehicles but may affect the replacement of existing vehicles. Consistent with this interpretation, Appendix Table E.1 shows shifts in the age distribution of the fleet, with reduced ownership

of tax-paying vehicles and increased ownership of tax-exempt vehicles, but no significant change in total vehicle ownership.

Changes in a fleet's age distribution can arise through three economic mechanisms: the purchase of new vehicles, scrappage, and the exchange of used vehicles. At the local level, an older fleet may therefore reflect (i) relatively fewer purchases of new vehicles, (ii) lower scrappage rates, or (iii) net inflows of older vehicles—that is, vehicles "imported" into the municipality being older than those "exported." Due to data limitations, we cannot directly observe, at each vehicle age, the shares of vehicles that are retained, traded, or scrapped. However, in Subsection 6.2, we assess the potential magnitude of spillovers arising from cross-border vehicle trade. In addition, Appendix Table E.2 examines these mechanisms by analyzing how exemption policies affect changes in the number of vehicles across vintage groups over a one-year period. We find that municipalities with the lowest exemption thresholds have relatively fewer very new vehicles, consistent with either lower retention or greater scrappage of these vehicles (i.e., fewer net "imports" or more scrappage). In contrast, these municipalities retain relatively more older vehicles, consistent with either greater net inflows of older vehicles or lower scrappage rates. These effects are strongest in the lowest exemption group.

Given advances in fuel and emissions technology and the declining effectiveness of catalytic converters with vehicle age, older vehicles are, on average, more polluting than newer ones. Consistent with this mechanism, Panel B of Table 1 shows that lower exemption-age policies increase the emissions intensity of the vehicle fleet, with potential implications for both global and local air pollution. Municipalities with a 10-year exemption threshold have, on average, 23% higher on-road CO_2 emissions per capita and 20% higher on-road NO_x emissions per capita than municipalities in the *de facto* no-exemption group. While CO_2 contributes to global climate change, NO_x is a precursor to smog and ground-level ozone, with more localized effects on air quality. For municipalities with a 15- to 20-year exemption threshold, the estimated effects on CO_2 and NO_x emissions are also positive but not statistically significant. Consistent with these emission patterns, satellite-derived measures indicate approximately 4% $(0.3, \mu g/m^3)$ higher $PM_{2.5}$ concentrations in municipalities with lower exemption thresholds. Satellite measures also show 7% and 8% higher CO concentrations for municipalities with 10-year and 15- to 20-year exemption thresholds, respectively. The relatively similar effects on ambient concentrations, despite larger effects on emissions under the 10-year exemption policy, may reflect the influence of pollution sources beyond transportation, as well as measurement limitations in satellite-derived measures, which are averaged across pixels that may span multiple municipalities. We address potential concerns about atmospheric

transport and dispersion across state borders in Subsection 6.2.

In Table 1, Panel C, we find that infant health outcomes are worse in municipalities subject to lower exemption-age policies. Relative to the *de facto* no-exemption group, the 10- and 15- to 20-year exemption thresholds are associated with reductions in the average 5-minute Apgar score of 0.17 and 0.07 points, respectively, indicating poorer newborn health. The 10-year threshold is also associated with an 8.21 per 1,000 live births higher rate of low birth weight (below 2,500 grams) and a 2.55 per 1,000 live births higher rate of very low birth weight. For the 15- to 20-year threshold, the low birth weight rate is 2.33 per 1,000 live births higher than the baseline, while the estimated effect on very low birth weight is not statistically significant. Finally, the estimated effects on 28-day infant mortality are imprecise, although the point estimates are also positive.

Heterogeneity Analysis. To investigate the potential equity implications of age-based exemption policies, we examine heterogeneous effects across racial groups and municipal income levels in Table 2. Panel A reports the estimated effects of low-exemption policies on the incidence of low and very low birth weight among mothers from different racial groups, namely: White, Non-white, and Black.[27] Although Black mothers are included in the Non-White category, we analyze this group separately given its high level of social vulnerability. While the national average rates of low and very low birth weight are similar for White and Non-white mothers, both statistics are substantially higher among Black mothers. The estimated differences across state borders indicate that municipalities subject to the lowest exemption-age policy exhibit larger effects on low birth weight among Black mothers than among other racial groups, suggesting that these policies may exacerbate existing disparities in infant health.

We further examine heterogeneous policy effects across municipalities with different income levels in Table 2, Panel B. While age exemption policies have broadly similar effects on fleet size, pollution, and infant health, their effects on fleet age differ systematically in the poorest municipalities, defined as those in the bottom tercile of the GDP per capita distribution. Under the 10-year exemption threshold, municipalities in the lowest tercile experience an increase in average vehicle fleet age of 0.89 years relative to higher-income municipalities under the same policy. This differential effect disappears under the 15-20-year exemption threshold. Regarding fleet size, under the 15-20-year policy, if anything, the poorest municipalities have 0.05 fewer vehicles per capita relative to wealthier municipalities, providing no evidence that exemption policies increase vehicle ownership among poorer households.

[27]The "Non-white" group aggregates information from the subgroups of Brazilian mothers who self-identify as Mixed-race (*"pardo"*), Black (*"preto"*), Native (*"indígena"*), or of Asian descent (*"amarelo"*).

Consistent with these fleet effects, poorer municipalities under the low exemption thresholds do not experience statistically significant increases in on-road CO_2 or NO_x emissions relative to the no-exemption group; if anything, the estimates under the 15-20-year exemption policy suggest a slight decrease. Finally, we find no significant differential effects of exemption policies on infant health outcomes in poorer municipalities.

6.2 Robustness Checks

We document a series of additional analyses and robustness checks in the Appendix that support our main findings. Using alternative pollution and infant health outcomes yields results consistent with our main analysis (Appendix Table F.2). Estimates based only on first-layer municipalities—i.e., the immediate pairs across the state line, which improves comparability at the cost of precision—are also similar to those in our main sample (Appendix Table F.3). Placebo exercises comparing municipalities across borders between states in the same exemption-regime group find no significant systematic differences between pairs subject to similar policies (Appendix Figure F.3). We also consider alternative empirical approaches, including regression discontinuity and difference-in-differences, in Appendix Sections F.3 and F.4, respectively. Across these analyses, the overall pattern of results remains broadly similar.

We discuss three sets of robustness checks in detail. The first examines potential cross-border spillovers from exemption policies. The second addresses concerns about the role of wind in determining pollution concentrations. The third reports coefficient estimates and confidence intervals under alternative sets of covariates.

Do exemption policies have spillover effects on municipalities' fleets across the border? An age-based exemption lowers the cost of owning tax-exempt vehicles, potentially increasing demand for exempt (or near-exempt) vehicles in local used-car markets. This raises a concern if consumers in a lower-exemption municipality purchase such vehicles from across the border, where they would remain taxable. These trades would mechanically age the fleet on the lower-exemption side and reduce it on the higher-exemption side, potentially causing our border-pair estimator to double-count the effect. Although we cannot directly observe cross-state vehicle transactions, quantitatively important spillovers should appear in aggregate fleet statistics when an exemption gap opens between paired areas.

We assess this possibility using policy changes in Tocantins (TO) and Mato Grosso do Sul (MS), comparing fleet trends across closer and more distant paired municipalities in neighboring states that initially shared the same exemption age. Before the policy changes, identical exemption thresholds imply no incentive for exemption-driven cross-border trade.

When one state raises its exemption age, however, such incentives may emerge, particularly among municipalities closer to the border. We therefore define paired Layer 1 municipalities as the "spillover-treated" group and Layer 2 municipalities as the comparison group.[28]

We implement this test using a DiD event-study design. Under no anticipation and parallel trends between Layer 1 and Layer 2 municipalities absent the neighboring state's policy change, differences in their post-policy trends capture the indirect effects of the exemption change. Importantly, identification does not require the absence of spillovers in Layer 2; it requires only that exposure be greater in Layer 1, as expected if distance limits cross-border trade.

Appendix Figure F.1 presents the results. We find no evidence of spillovers: following the neighboring state's policy change, Layer 1 municipalities exhibit no significant changes relative to Layer 2 in fleet age, vehicles per capita, or ownership of vehicles in the affected age groups. Had cross-border trade been quantitatively important, we would expect Layer 1 municipalities to acquire more of the older vehicles that became tax-exempt across the border, thereby aging their fleets and increasing vehicle ownership.

Can the pollution concentration estimates be driven by wind-carried pollution? A potential concern with our satellite-based pollution estimates is that wind could transport vehicle emissions across state borders, contaminating comparisons between municipalities under different exemption regimes. If wind flows from high- to low-exemption jurisdictions, it could reduce pollution on the expected low-pollution side and increase it on the expected high-pollution side, overstating the estimated policy effect. The opposite flow could attenuate the estimated effect. We address this concern using evidence from the literature and an empirical analysis of cross-border wind patterns.

Unlike industrial and power plant emissions, which are released from elevated smokestacks and can travel long distances (Morehouse and Rubin, 2026), vehicular emissions typically dissipate to near-background levels within about one-third of a mile (Karner et al., 2010). Given that the average distance from a municipality centroid to the border is 26.2 miles, the rapid spatial decay of vehicle-related pollutants makes substantial wind-driven contamination unlikely. Nevertheless, we directly test this possibility by exploiting variation in wind direction and speed.

We construct municipality-by-year measures of wind direction and speed from the U and V

[28]For TO, the spillover sample consists of paired Layer 1 municipalities in Bahia (BA), Maranhão (MA), Pará (PA), and Piauí (PI). For MS, it consists of paired Layer 1 municipalities in Paraná (PR).

wind components.[29] We combine these measures with the direction to each municipality's matched border-layer pair and aggregate them to the border-layer level using the modal direction. We define potential cross-border transport as cases in which wind flows from one layer toward its pair and the same directional pattern holds on both sides of the border, identifying a consistent "source" and "receiver" pair. Focusing on borders separating different exemption regimes, we re-estimate our main specification with interactions for cross-border wind flows, distinguishing high-to-low from low-to-high exemption directions. We also examine heterogeneity by above- versus below-median wind speed.

Appendix Table F.1 shows that our main results are largely unchanged when accounting for cross-border wind flows. The exemption-age coefficients closely mirror our baseline estimates, and we generally find no significant differential effects associated with potential wind-driven transport in either direction. Finally, the pollution gap across borders is larger in municipalities with lower average wind speeds, consistent with stronger winds dispersing pollutants and reducing spatial concentration differences. Overall, these results suggest that cross-border wind transport is unlikely to drive our pollution estimates.

Coefficient stability. Our main specification includes controls for five categories of potential confounders, as described in Section 5: (i) *IPVA* tax rates by vehicle type, (ii) geography, (iii) local and state economic conditions and policies, (iv) environmental variables, and (v) local health infrastructure. We assess coefficient stability by progressively adding each group of controls and examining how the estimates of our main parameters of interest change.

Appendix Figure F.2, Panel (a), reports estimates of the effect of low exemption-age thresholds on fleet age. The baseline specification, which controls for *IPVA* tax rates and geography, yields positive effects that are largest for the lowest exemption-age group. This pattern persists as additional controls are added. While including local policies and economic conditions substantially reduces the standard errors, the point estimates remain within the confidence intervals of earlier specifications and are highly stable through the fully specified model.

The remaining panels of Appendix Figure F.2 examine selected pollution and health outcomes. Estimates for on-road NOx emissions per capita are particularly stable for the lowest exemption-age group, with little change between the simplest and fully specified models. Estimates for the 15-20 year exemption-age group vary somewhat with the addition of controls but remain consistently smaller in magnitude. Results for $PM_{2.5}$ concentrations and the

[29] The U and V wind components describe wind as two perpendicular movements. The U component captures east-west movement (positive values indicate wind blowing east, negative values indicate west), while the V component captures north-south movement (positive values indicate wind blowing north, negative values indicate south). Together, they provide a complete representation of wind direction and intensity.

5-minute Apgar score are likewise stable across specifications, with estimates from the fully specified model remaining well within the confidence intervals of the initial specifications. Overall, these results indicate that our findings are robust to the progressive inclusion of controls, which, as expected, primarily improves precision without substantially changing the point estimates.

7 Political Economy and Fiscal Implications

Despite reducing states' tax bases and distorting consumer incentives, with adverse environmental and health consequences, anti-scrappage policies—particularly vehicle-age exemptions—remain in place in most Brazilian states. Political incentives at the local level may help explain their adoption and persistence. Because voting is mandatory in Brazil, if the median voter places greater value on the lower expected tax burden associated with older vehicles than on the public goods financed by tax revenues, the electoral system may favor maintaining these exemptions. Over time, this dynamic may become self-reinforcing: as the share of older, tax-exempt vehicles grows, so too may political support for maintaining the exemptions. Such a process can create a "political environmental trap," in which environmentally harmful policies become increasingly entrenched (Delfgaauw and Swank, 2024).

7.1 Electoral Impacts of Policy Change

We examine whether changes in vehicle-age exemptions under the *IPVA* affect electoral outcomes and whether these effects vary with the composition of the local vehicle fleet. Changes in exemption thresholds are enacted through state legislation, with proposals originating from either the governor or the legislative assembly. We focus on changes occurring during the 2014-2018 election cycle and examine their effects on first-round vote shares for gubernatorial and state legislative candidates affiliated with the incumbent governor's party.

Our analysis exploits three policy changes. In 2015, Goiás (GO) raised its exemption threshold from 10 to 15 years, while Mato Grosso do Sul (MS) raised it from 15 to 20 years, with both changes taking effect in 2016. We use these reforms to study increases in the exemption threshold, which expand the set of exempt vehicles. Conversely, Mato Grosso (MT), which previously had no age-based exemption, introduced an exemption for vehicles older than 18 years in 2017, effective in 2018. This reform provides the corresponding case of introducing an exemption. GO subsequently returned to a 10-year threshold in 2018, but the change took effect only in 2019, after the election. We exclude Tocantins (TO), which removed its exemption in 2015, because subsequent political shocks prevent us from separately identifying

the electoral effects of the policy change.[30]

The electoral effects of these reforms depend on which vehicle owners are affected. When the exemption threshold increases, owners of vehicles that become newly taxable face a direct increase in expected tax liabilities, while owners of vehicles that were already taxable face a longer expected period of taxation. Conversely, introducing or lowering an exemption threshold reduces expected tax liabilities for affected vehicle owners. We therefore exploit differences in the age composition of local vehicle fleets to measure municipalities' exposure to each reform.

Our empirical strategy is a triple-difference design that combines changes in electoral outcomes over time, differences between states that did and did not change their exemption policies, and predetermined differences in local fleet composition. A simple difference-in-differences comparison between reforming and non-reforming states could be confounded by state-level factors that influence both policy decisions and electoral outcomes, such as fiscal conditions or public service provision. Variation in fleet composition provides an additional source of heterogeneity that is plausibly predetermined: although exemption policies and elections are determined at the state level, the age structure of a municipality's vehicle fleet reflects historical local conditions and is unlikely to have been chosen in response to the reform. To improve comparability, we use our border-layer pairing approach to construct matched samples of municipalities located across state borders.

We estimate the following specification:

$$y_{c,m,t} = \alpha Ch_{S,t} + \pi Veh_{m,t} + \gamma(Ch_{S,t} \times Veh_{m,t}) + X'_{m,t}\vartheta + \eta_m + \delta_t + \varepsilon_{c,m,t}, \tag{4}$$

where $y_{c,m,t}$ is the percentage of votes received by candidate c from the incumbent governor's party in municipality m and election year t. $Ch_{S,t}$ indicates whether state S changed its *IPVA* age threshold during the preceding four-year election cycle, while $Veh_{m,t}$ captures the age composition of the local vehicle fleet. Our coefficient of interest, γ, measures whether the electoral effect of a policy change varies with local fleet composition. The specification includes municipality and year fixed effects, η_m and δ_t, as well as the municipality-year controls $X_{m,t}$ used in our border-pair analysis.

We estimate the effects of increases and decreases in the exemption threshold separately. For the threshold increases in GO and MS, we compare treated municipalities with border-paired

[30]These shocks include a political scandal involving campaign finance irregularities, the removal of the incumbent governor by the electoral court in 2018, and a subsequent low-turnout special election. Further details on the political processes and timing of these reforms are provided in Appendix G.

municipalities in Bahia (BA), Distrito Federal (DF), Minas Gerais (MG), Paraná (PR), and São Paulo (SP). For the introduction of an exemption in MT, the comparison municipalities are located in Amazonas (AM), Pará (PA), and Rondônia (RO).

The results, reported in Table 3, indicate that changes in exemption policies have electoral consequences. In Panel A, governing-party candidates receive lower vote shares in municipalities with a larger share of vehicles that remain taxable following the increases in the exemption age in GO and MS. This effect reflects two channels: vehicles that were already taxable face a longer expected duration of taxation, while vehicles that newly lose their exemption face a direct increase in expected taxation. Although the former group represents a larger share of the fleet, the electoral response is stronger among owners whose vehicles newly lose exemption status. A one-percentage-point increase in the share of vehicles losing their exemption is associated with a 2.3 percentage-point reduction in the incumbent party's gubernatorial vote share and a 0.15 percentage-point reduction in its state legislative vote share. These estimates correspond to approximately 1.8 fewer gubernatorial votes and 0.1 fewer state legislative votes for each vehicle that loses exemption status.[31] The stronger response among newly taxable vehicles is consistent with a "political environmental trap," whereby policies that increase the effective cost of vehicle ownership generate particularly strong political opposition.

The opposite reform in MT provides more limited but broadly consistent evidence, as shown in Panel B. Under a simple self-interest framework, vehicle owners benefiting from the newly introduced exemption should favor the reform. Although the estimates for gubernatorial candidates are positive but statistically insignificant, governing-party state legislative candidates gain votes in municipalities with a larger share of vehicles that become newly exempt. The estimates are noisier in this case because the reform involves fewer treated units.

Given the limitations of the data and research design, we interpret these results as suggestive evidence that the distributional consequences of vehicle-age exemptions create political incentives around anti-scrappage policies. More broadly, the findings are consistent with evidence that voters respond negatively to local tax increases (Donovan et al., 2024) and with the broader literature on the political constraints facing more efficient environmental taxation, particularly in fuel and energy markets (Hammar et al., 2004; Agostini and Jiménez, 2015; Carattini et al., 2017).

[31] See Appendix G for details on this back-of-the-envelope calculation.

7.2 Fiscal Effects of Policy Change

We examine how changes in exemption-age thresholds affect government revenue and public healthcare expenditures. Our outcomes are municipal *IPVA* revenue per vehicle and public healthcare expenditures per capita. Municipalities retain half of the *IPVA* collected from vehicles owned by residents, with the remaining half accruing to the state government. We consider both the average effect of changing the exemption threshold and the marginal effect of changing the share of vehicles that gain or lose exemption status.

We use a difference-in-differences design comparing changes in fiscal outcomes between states that changed their exemption thresholds and border-paired municipalities in neighboring states that did not. Although the effect of an exemption change on the tax base is largely mechanical, vehicle owners may respond by changing vehicles or complying differently with the tax, so our estimates capture the overall effect on realized tax revenue. We first examine the threshold increases in Goiás (GO) and Mato Grosso do Sul (MS), using the same border-paired comparison municipalities as in the electoral analysis. We then apply the same approach to the exemption introduced in Mato Grosso (MT). We estimate:

$$y_{m,t} = \varphi Treated_{mt} + X'_{m,t}\vartheta + \eta_m + \delta_t + \nu_{m,t}, \tag{5}$$

where $y_{m,t}$ denotes *IPVA* revenue per vehicle or public healthcare expenditures per capita in municipality m and year t. In the first specification, $Treated_{mt}$ indicates whether the municipality was exposed to a change in the exemption threshold. In the second, it measures the percentage of the local fleet that lost or gained exemption status as a result of the reform. Both specifications include municipality and year fixed effects and the municipality-year controls used in the border-pair analysis.

The results, reported in Table 4, show that raising the exemption threshold generated additional revenue and was associated with lower healthcare expenditures. In Panel A, the five-year increases in the exemption age in GO and MS increased annual *IPVA* revenue by \$35.8 BRL per vehicle, or \$17.9 BRL accruing to each level of government, and reduced public healthcare expenditures by \$38.2 BRL per capita. Because municipalities are required to devote a minimum share of revenue to public health, the increase in tax revenue would mechanically raise the health-spending floor; the decline in expenditures therefore likely reflects changes in healthcare demand rather than reduced fiscal capacity.[32] We find no statistically significant effect on *IPVA* revenue in MT following the introduction of an exemption for

[32]Municipalities are required to apply at least 15% of their revenue, including transfers from higher levels of government, to public health actions and services (Constitutional Amendment 29/2000).

vehicles older than 18 years. Because MT experienced different pre-reform fleet dynamics from its neighboring states, we interpret this result cautiously.

Panel B examines the effects of marginal changes in the vehicle tax base. Each percentage-point increase in the share of vehicles losing exemption status increased annual consolidated *IPVA* revenue per vehicle by \$2.48 BRL, or approximately 1.5%. This corresponds to roughly \$248 BRL in additional annual revenue for each vehicle that lost its exemption.[33] At the same time, a one-percentage-point increase in the share of taxable vehicles was associated with an approximately 0.5% reduction in public healthcare expenditures per capita.

7.3 Political Costs of Revenue Raised

From the perspective of vehicle owners, *IPVA* exemptions resemble a targeted government transfer. Previous research shows that government transfers can increase political support for incumbents associated with those policies (Manacorda et al., 2011; De La O, 2013; Zucco Jr, 2013). Increasing the *IPVA* exemption age in GO and MS therefore represents a reversal of a previously received benefit and may generate electoral backlash among affected voters.

Combining our fiscal and electoral estimates allows us to quantify this fiscal-political trade-off. In GO and MS, where the exemption threshold increased by five years, a one-percentage-point increase in the share of vehicles losing exemption reduced the incumbent party's gubernatorial vote share by 2.3 percentage points while increasing annual *IPVA* revenue by approximately 1.5%. Thus, among the states in our sample, a 1% increase in *IPVA* revenue was associated with a 1.5 percentage-point reduction in the incumbent party's gubernatorial vote share.

We can also express this trade-off in monetary terms. Our back-of-the-envelope estimates imply that each vehicle losing its exemption generated approximately \$248 BRL in additional annual revenue and was associated with 1.77 fewer votes for the incumbent party. Thus, each additional vote retained by maintaining the more generous exemption policy corresponds to approximately \$248/1.77 = \$140 BRL in forgone annual revenue. This pattern is consistent with a model of *rational but poorly informed* voters in which the benefits individuals receive from government transfers provide information about the government's redistributive preferences toward "people like them" (Manacorda et al., 2011).

These magnitudes help explain the political resistance to expanding the vehicle tax base.

[33] Revenue per affected vehicle is calculated as $2 \times \frac{\varphi_{mrg}\sigma_{pp}N_{Veh}}{(\sigma_{pp}/100)N_{Veh}} = 200\varphi_{mrg}$, where φ_{mrg} is Panel B level-regression coefficient, σ_{pp} is the percentage-point share of vehicles losing exemption, and N_{Veh} is the fleet size. The fraction captures the municipal revenue added by each vehicle, but *IPVA* is shared equally between state and local governments; thus total revenue gained among all state entities is re-scaled by 2.

Although the reforms in GO and MS increased *IPVA* revenue by roughly 21%, the resulting increase in total state tax revenue was only about 1%.[34] The costs of the reform, however, were concentrated among affected vehicle owners. For owners whose vehicles lost exemption status, the reform generated a discrete increase in tax liability from zero to an amount equivalent to roughly 2% of average annual worker income, as mentioned in Section 2. Moreover, because the reform reversed long-standing expectations about exemption eligibility, affected voters may respond more strongly to the loss than to an equivalent gain, consistent with reference dependence and loss aversion (Tversky and Kahneman, 1991).

7.4 MVPF of Age-Based Exemption Policies

The marginal value of public funds (MVPF) framework introduced in Section 3 provides a way to evaluate the welfare effects of age-based vehicle tax exemptions. The MVPF compares the societal value of a policy—including beneficiaries' private gains and external costs borne by others—with its fiscal cost, as defined in Equation (1). An MVPF of 1 corresponds to a non-distortionary lump-sum transfer, for which the policy's benefits equal its fiscal cost.

The MVPF depends on four sufficient statistics: (i) the average value of vehicles at the exemption margin, (ii) the mass of vehicles at the exemption threshold, (iii) the response of health-related costs to the policy, and (iv) the response of tax revenue. We estimate each using the five-year exemption-threshold increases in Goiás (GO) and Mato Grosso do Sul (MS). We summarize the calculations below and provide details in Appendix H.[35]

We first quantify the private benefit of a more generous exemption. Lowering the age threshold—or, equivalently, avoiding an increase in the threshold—provides tax relief to owners of vehicles at the exemption margin. Combining the estimated value and number of vehicles in the marginal age bins with each state's tax rate yields a willingness to pay of approximately \$48.50 BRL per vehicle, or \$24.25 BRL per capita. Relative to the \$35.80 BRL per-vehicle increase in consolidated tax revenue generated by the five-year threshold increase (Table 4), the private benefit amounts to \$1.35 for each \$1 of revenue foregone.

The private benefits, however, are more than offset by the health externalities associated with a more generous exemption. Using the estimated response of municipal healthcare expenditures to the reform (Table 4) as a revealed-preference proxy for the population's

[34] Between 2013 and 2015, *IPVA* accounted for approximately 6% and 4% of total state tax revenue in GO and MS, respectively.

[35] We use GO and MS to maintain consistency with the electoral analysis. Mato Grosso (MT) is excluded because its fleet dynamics differed from those of its comparison group before the policy change, making it unsuitable for the MVPF calculation.

willingness to pay to avoid the associated pollution, we estimate an external cost of $38.20 BRL per capita. Relative to the $17.90 BRL per-capita fiscal cost of the exemption, this implies an additional welfare loss of $2.13 for each $1 of revenue foregone.

Combining the private benefit and health externality yields the MVPF of a five-year reduction in the *IPVA* exemption threshold:

$$MVPF = \frac{\tau V(\bar{a}) f(\bar{a}; \bar{a})}{dR/d\bar{a}} - \kappa \frac{dH/d\bar{a}}{dR/d\bar{a}} \approx 1.35 - 2.13 = -0.78.$$

Thus, for each $1 BRL of revenue foregone by state and local governments, the policy generates an additional $0.78 BRL in welfare losses. Although the exemption generates substantial benefits for the small group of marginally exempt vehicle owners—approximately $200 BRL per beneficiary—these gains are concentrated among beneficiaries, while the health costs are dispersed across the broader population. The resulting negative MVPF reflects the fact that the latter outweighs the former.

The MVPF also provides a common metric for comparing the welfare consequences of alternative uses of public funds. The MVPF of -0.78 for a five-year reduction in the exemption threshold is substantially below the MVPFs reported for most of the 133 U.S. policies evaluated by Hendren and Sprung-Keyser (2020), including cash transfers, income tax benefits, and health policies. For comparison, using the estimated MVPF of 1.45 for electric-vehicle subsidies in Hahn et al. (2026) implies that reallocating $1 BRL from age-based *IPVA* exemptions to EV subsidies could generate up to $2.23 BRL in additional welfare. Similarly, using the MVPF of 2.5 estimated for *Programa Bolsa Família* (PBF) by Gerard et al. (2026) implies potential welfare gains of up to $3.28 BRL for each $1 BRL redirected from age-based *IPVA* exemptions to an equivalent PBF-type policy.

8 Concluding Remarks

Governments often adopt policies to improve equity that can inadvertently weaken environmental incentives. The transportation sector illustrates this tension particularly clearly. While an ideal policy would price vehicle use according to its pollution and other externalities, such measures are often politically difficult to implement and enforce, especially in low- and middle-income countries. Governments instead frequently rely on vehicle taxes and fees that decline with vehicle age, reducing the cost of keeping older, more polluting vehicles on the road. Brazil's vehicle ownership tax (*IPVA*) is a prominent example: vehicles older than a state-specific threshold are exempt from the tax, weakening incentives to retire older

vehicles and prolonging the operation of a disproportionately polluting segment of the fleet.

Using a border-pair design, we identify the effects of these age-based exemptions on vehicle fleets, pollution, health, fiscal outcomes, and political behavior. We find that lower exemption thresholds generate substantially larger distortions in the age of the vehicle fleet. Exemption thresholds of 15-20 years increase average vehicle age by approximately 0.5 years, whereas a 10-year threshold increases it by about one year. We also find evidence that more generous exemptions increase pollution emissions and concentrations near state borders and are associated with worse infant health outcomes.

These environmental and health costs do not appear to be offset by greater vehicle ownership among lower-income households, despite affordability being a common justification for age-based exemptions. We find no effect on vehicles per capita. Moreover, the effects differ across the income distribution: the oldest fleets are concentrated in the poorest municipalities under the lowest exemption threshold, while we find little evidence of an age effect among poor municipalities under the 15-20-year thresholds. Taken together, the results are consistent with owners extending the life of vehicles they would have owned regardless of the exemption, rather than the policy substantially expanding vehicle ownership. The exemption therefore operates more like a transfer to owners of older vehicles while generating local pollution, health, and global environmental costs.

The distribution of these benefits and costs also creates substantial political resistance to reform. Although raising exemption thresholds increases tax revenue and can reduce health-care expenditures, affected vehicle owners bear concentrated and salient costs. Consistent with this mechanism, we find that incumbent-party candidates lose electoral support in municipalities with a larger share of vehicles that lose their exemption. Our fiscal and electoral estimates imply that each vehicle losing its exemption generates approximately \$248 BRL in additional annual *IPVA* revenue but is associated with roughly 1.8 fewer votes for the incumbent party. These political costs help explain why policies that are inefficient from a social perspective can nevertheless be difficult to reverse. Indeed, in December 2025, Brazil adopted a constitutional amendment establishing a nationwide *IPVA* exemption for vehicles at least 20 years old, explicitly framed in terms of reducing tax burdens and addressing perceived fiscal inequities across states.

Our welfare analysis reinforces this tension. The MVPF of a five-year reduction in the exemption threshold is estimated at -0.78: for every \$1 BRL of revenue forgone, the policy generates an additional \$0.78 BRL in welfare losses. The private benefits of exemption are concentrated among a relatively small group of vehicle owners, while the associated health

costs are dispersed across the broader population. Thus, policies designed to improve the affordability of vehicle ownership can ultimately undermine both equity and efficiency when they subsidize the continued use of older, more polluting vehicles.

The policy challenge is therefore not to eliminate support for vehicle affordability, but to target it without weakening incentives to replace older vehicles. Brazil has previously used fiscal and credit policies to make newer vehicles more affordable while promoting particular vehicle technologies. In the 1990s, for example, the federal government introduced the "popular car" policy, which sharply reduced the federal tax on industrialized products (IPI) for small-engine vehicles, helping expand the market for more affordable models such as Volkswagen Gol. In the early 2000s, IPI rates were further differentiated by engine size and fuel type, with lower rates for alcohol-fueled vehicles, helping support the expansion of the ethanol vehicle market and the subsequent introduction of flex-fuel vehicles. More recently, the MOVER Program has linked federal vehicle taxation more explicitly to environmental characteristics, including propulsion technology, energy efficiency, recyclability, and carbon footprint, with more favorable tax treatment for vehicles meeting stronger environmental criteria. In parallel, the Move Brasil Program provides financing on favorable terms for the purchase of new vehicles by taxi and app-based drivers, with eligibility focused on vehicles using lower-emission technologies such as electric, hybrid, flex-fuel, and ethanol propulsion. Together, these policies illustrate an alternative approach: rather than subsidizing the continued use of older vehicles, governments can direct fiscal and financial support toward the purchase of newer, cleaner, and more efficient vehicles.

More broadly, our results suggest that vehicle taxation should account for both the environmental costs of vehicle use and the distributional consequences of reform. Gradually reducing age-based exemptions while using targeted support to protect lower-income households—and differentiating taxes on new vehicles according to environmental performance—could preserve affordability goals without locking in incentives to retain older, more polluting vehicles. Such reforms would better align vehicle taxation with environmental and health objectives while recognizing the political constraints that shape the feasibility of environmental policy.

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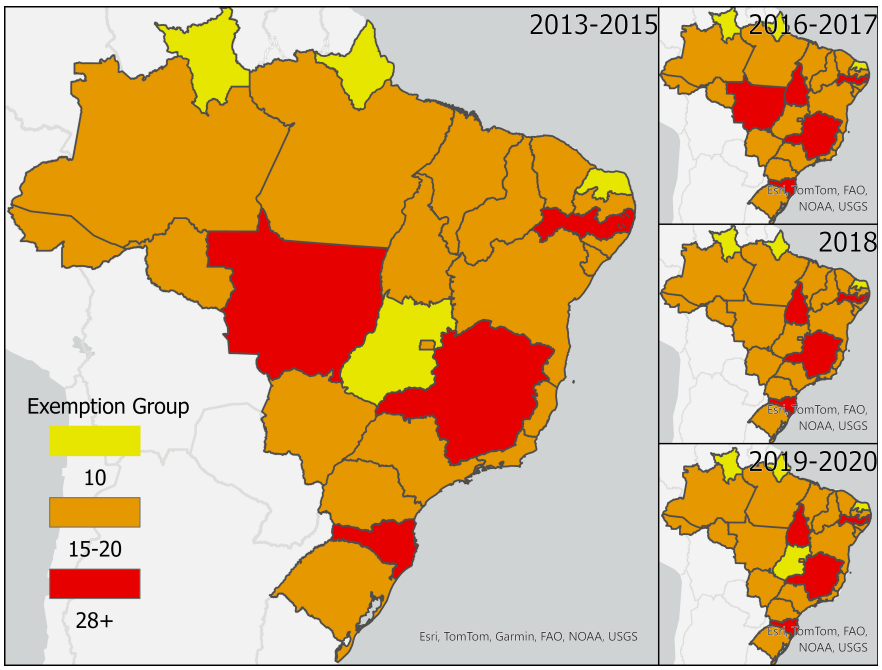
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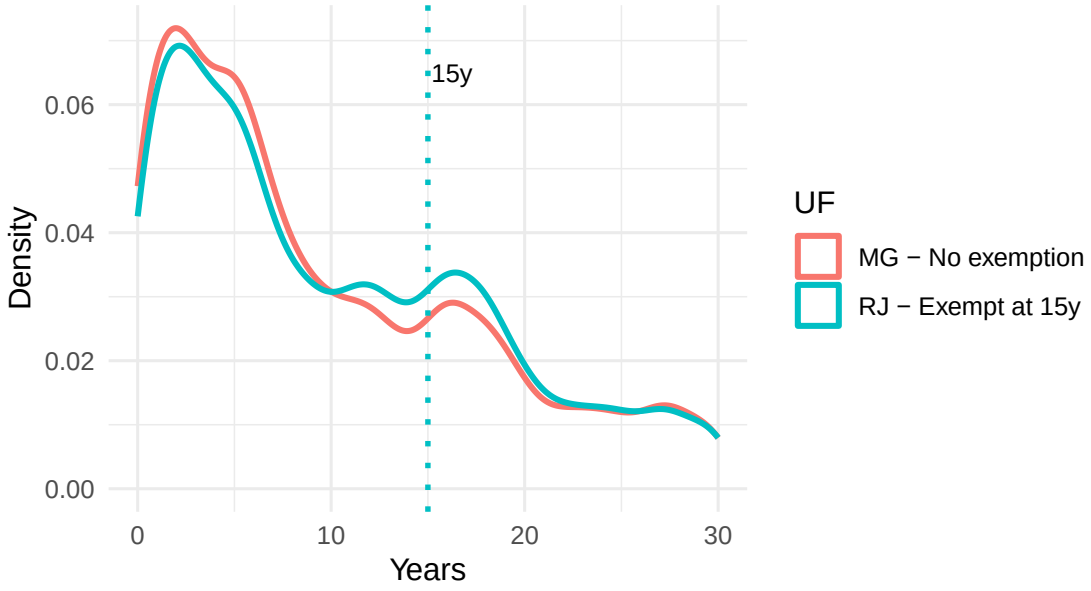
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Figures and Tables

Figure 1: States Exemption Age Thresholds and Fleet Age Density



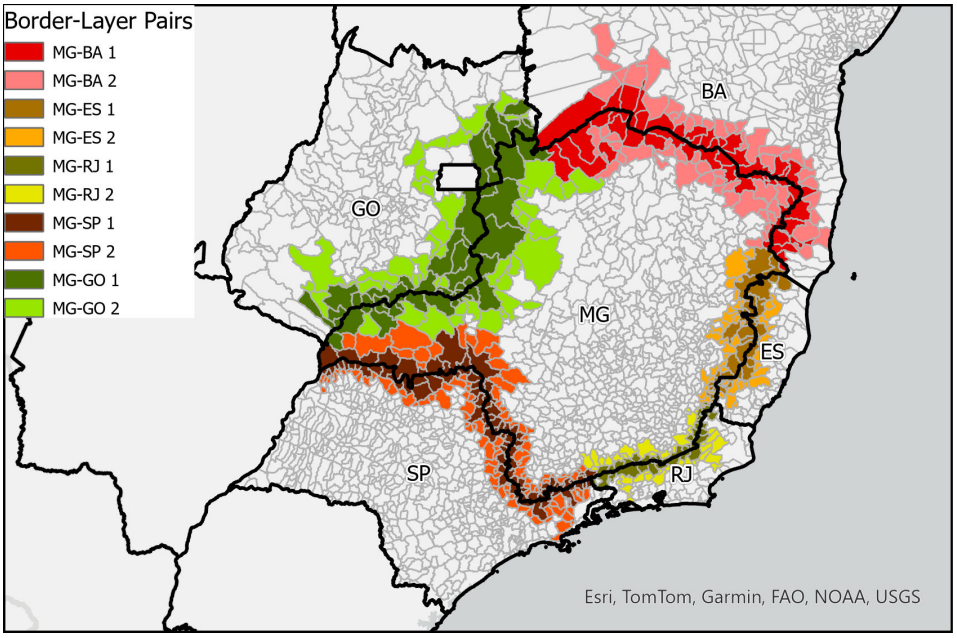
(a) Maps of Exemption Age Threshold, 2013-2020



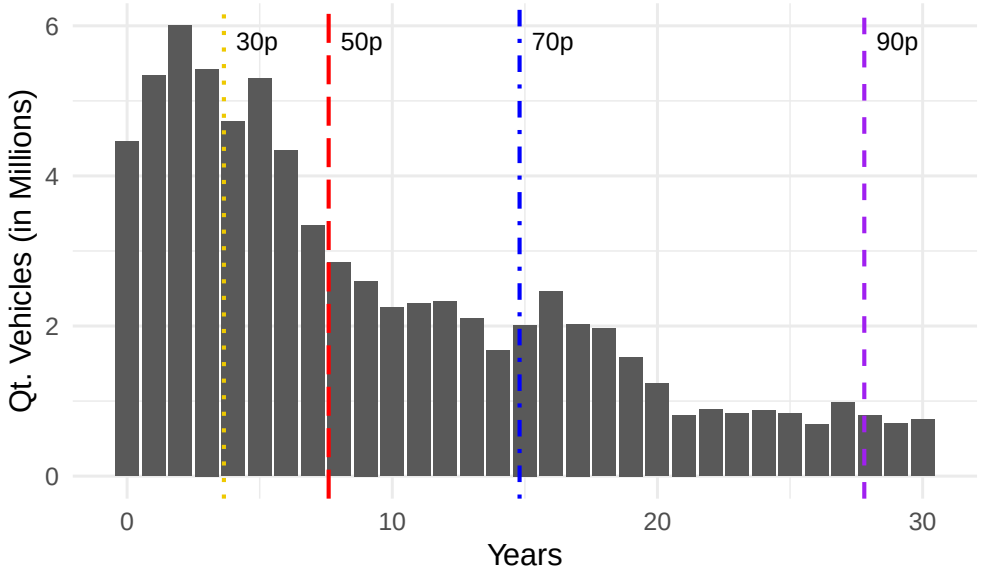
(b) Two-State Example: Density of Fleet Age, 2013

Notes: Panel (a) presents a map of exemption age thresholds across Brazilian States from 2013 to 2020. Panel (b) provides a didactic example of the age distribution of vehicle fleets in two states—Minas Gerais (MG) and Rio de Janeiro (RJ)—that adopt different age-based exemption policies. Panel (b) uses state-level aggregate information on number of vehicles by age from RENAVAM, with smooth density functions calculated with gaussian kernel of 1-year bandwidth. Graph is limited to 30 years for readability.

Figure 2: Paired Border-Layers and National Fleet by Age



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



(b) Vehicles by Age, 2013

Notes: Panel (a) presents a didactic example of paired border-layers around the state of Minas Gerais (MG). Darker tones of color indicate first layer level, lighter tones represent second layer level. Each border-layer pair is the group of municipalities with same color (and tone): for example, dark green municipalities indicate the "MG-GO 1" pair. Panel (b) is an histogram of vehicles by age for the whole county in 2013. Bars are total number of vehicles (in million) at each age. The 30th, 50th, 70th, and 90th age percentiles of the fleet are indicated in the graph as the following: yellow dotted line (3.7 years), red long-dashed line (7.6 years), blue dotted-and-dashed line (14.8 years), and purple dashed line (27.8 years). Graph is limited to 30 years for readability.

Table 1: Policy Impacts 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	1.00***	6.19***	2.77***	0.02
	(0.25)	(1.27)	(0.72)	(0.03)
Exemption Age: 15-20	0.43**	1.93**	1.85***	-0.01
	(0.17)	(0.80)	(0.53)	(0.02)
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	0.851	0.828	0.831	0.815
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.004	0.000	0.084	0.085
Panel B: Pollutants				
Dependent Variables:	Log CO_2 pc (Road)	Log NOx pc (Road)	Log $PM_{2.5}$	Log CO
Exemption Age: 10	0.23**	0.20*	0.04**	0.07**
	(0.11)	(0.11)	(0.02)	(0.03)
Exemption Age: 15-20	0.03	0.05	0.04***	0.08***
	(0.07)	(0.09)	(0.01)	(0.02)
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	0.618	0.608	0.936	0.839
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.035	0.049	0.681	0.333
Panel C: Infant Health				
Dependent Variables:	Average 5-min Apgar	Low Birth Weight	Very Low Birth Weight	28 Days Infant Mortality
Exemption Age: 10	-0.17***	8.21***	2.55***	0.57
	(0.05)	(1.22)	(0.40)	(0.36)
Exemption Age: 15-20	-0.07**	2.33**	0.24	0.09
	(0.03)	(1.02)	(0.23)	(0.14)
Regression Statistics				
Mean Dep. Variable:	9.36	81.19 (per 1000)	12.79 (per 1000)	7.96 (per 1000)
Observations	19,357	19,357	19,357	19,357
R^2	0.358	0.269	0.140	0.099
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.020	0.000	0.000	0.146

Notes: This table presents border-pair approach estimates of the average impact of low age-exemption thresholds on fleet, pollution, and infant health outcomes relative to *de facto* no-exemption policy. Sample is composed of municipalities in first and second layer levels observed from 2013 to 2020. We present the coefficients for the exemption age group dummies from estimating Equation 2 via OLS. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions feature our full set of controls—including controls for vehicle specific tax rates, geography and weather, local economy and policies, environmental-related variables, and healthcare infrastructure—as detailed in Section 5. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 2: Heterogeneous Impacts of Policy across Equity Lines

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Infant Health by Mother's Race						
Dependent Variables:	Low Birth Weight			Very Low Birth Weight		
	White Mother	Non-White Mother	Black Mother	White Mother	Non-White Mother	Black Mother
Exemption Age: 10	10.78**	7.68***	32.03***	1.46	2.50***	7.29***
	(5.08)	(2.48)	(10.31)	(1.53)	(0.59)	(2.38)
Exemption Age: 15-20	3.70	3.64**	2.36	0.05	0.23	1.02
	(3.16)	(1.62)	(5.38)	(1.06)	(0.28)	(1.05)
Regression statistics						
Mean Dep. Variable (per 1,000):	82.13	84.73	92.92	13.78	13.39	16.01
Observations	15,676	15,676	15,676	15,676	15,676	15,676
R^2	0.105	0.181	0.089	0.070	0.096	0.079
Panel B: By Municipalities GDP per capita						
Dependent Variables:	Vehicle Fleet		Log Emissions		Infant Health	
	Average Age	Vehicles per capita	CO_2 (Road)	NOx (Road)	5-min Apgar	Low Birth Weight
Exemption Age: 10	0.49**	0.01	0.14	0.10	-0.16***	8.21***
	(0.24)	(0.03)	(0.11)	(0.11)	(0.06)	(1.42)
Exemption Age: 10 × Poor Municipality	0.89***	-0.01	-0.01	-0.02	-0.04	-1.84
	(0.33)	(0.02)	(0.10)	(0.14)	(0.06)	(2.11)
Exemption Age: 15-20	0.51***	0.00	0.07	0.10	-0.06*	2.70***
	(0.15)	(0.02)	(0.06)	(0.08)	(0.03)	(0.96)
Exemption Age: 15-20 × Poor Municipality	-0.55*	-0.05***	-0.24***	-0.30**	-0.03	-1.96
	(0.30)	(0.02)	(0.08)	(0.11)	(0.04)	(1.60)
Regression statistics						
Mean Dep. Variable:	12.1	0.45	-0.32	-5.61	9.36	81.19
Observations	19,357	19,357	18,942	18,944	19,357	19,357
R^2	0.856	0.825	0.633	0.621	0.358	0.270
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.910	0.723	0.462	0.944	0.050	0.000
F-Test: $\beta_{10} + \lambda_{10} = \beta_{15-20} + \lambda_{15-20}$ (p-value)	0.000	0.001	0.000	0.000	0.021	0.000
F-Test: $\beta_{10} + \lambda_{10} = 0$ (p-value)	0.000	0.991	0.104	0.479	0.001	0.000
F-Test: $\beta_{15-20} + \lambda_{15-20} = 0$ (p-value)	0.882	0.004	0.016	0.036	0.046	0.647

Notes: This table presents the heterogeneous impacts of age-based exemption policies across racial groups and municipalities with different past levels of income, estimated using the border-pair approach. Panel A reports results separately for White, Non-White, and Black mothers, with Black mothers included in the Non-White group but analyzed separately due to their high level of social vulnerability. The analysis in this panel uses a subsample of municipality-years for which birth outcomes are available for all subgroups analyzed. Estimates are obtained by estimating Equation 2 via OLS. Panel B is estimated from Equation 3 via OLS using the full border-pair sample (layers 1-2 in years 2013-2020). Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 3: Political Economy Implications of Changing Exemption Age Threshold

Dependent Variable:	Vote Share (%)			
	Governor		State Assembly	
Model:	(1)	(2)	(3)	(4)
Panel A: GO and MS raised exemption age				
Raised Age × Vehicles Under New Exemption (%)	-0.56*		-0.03**	
	(0.31)		(0.01)	
Raised Age× Vehicles Lost Exemption (%)		-2.3*		-0.15*
		(1.2)		(0.09)
Regression statistics				
Mean Dep. Variable:	25.7 (%)	25.7 (%)	0.75 (%)	0.75 (%)
Observations	407	407	13,237	13,237
R^2	0.972	0.972	0.025	0.025
Panel B: MT lowered exemption age				
Lowered Age × Vehicles Under New Exemption (%)	1.4		-0.28	
	(1.7)		(0.40)	
Lowered Age× Vehicles Gained Exemption (%)		0.27		0.45**
		(0.54)		(0.20)
Regression statistics				
Mean Dep. Variable:	30.9 (%)	30.9 (%)	0.62 (%)	0.62 (%)
Observations	193	193	484	484
R^2	0.904	0.902	0.372	0.372

Notes: This table presents electoral implications of changes to the states' age-based exemption policies using a triple-difference design. In Panel A, "treated" states are MS and GO, while "control" states are BA, DF, MG, PR, and SP. In Panel B, "treated" state is MT, and "control" states are AM, PA, RO. Observations are at the candidate-municipality-year level using 2014 and 2018 elections data from Brazil's Superior Electoral Court (TSE). Sample includes municipalities of layer levels 1,2, and 3 from the paired border-layers from the "treated" states that changed policy between election and the neighboring "control" status that kept status quo. Results are obtained by estimating Equation 4 via OLS. Standard-errors are clustered at the municipality level. All regressions are weighted by municipality-share of total votes in state. All regressions include municipality and year fixed effects in addition to the full set of municipality-year-varying controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table 4: Effects of Policy Change on Municipal *IPVA* Revenue and Public Healthcare Expenditures

Treated States (and Time-Period):	GO, MS (2013-2018)				MT (2013-2020)			
Dependent Variables:	*IPVA* Revenue per vehicle		Health Expenditures per capita		*IPVA* Revenue per vehicle		Health Expenditures per capita	
	Level	Log	Level	Log	Level	Log	Level	Log
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Change in threshold								
Raised Age	17.9***	0.214***	-38.2***	-0.071***				
	(2.35)	(0.023)	(10.1)	(0.020)				
Lowered Age					1.54	0.016	39.2***	0.037
					(1.84)	(0.021)	(14.3)	(0.027)
Regression statistics								
Mean Dep. Variable	$97.4 BRL	4.51	$599.6 BRL	6.32	$85.7 BRL	4.40	$562.7 BRL	6.25
Observations	1,774	1,774	1,774	1,774	1,260	1,260	1,260	1,260
R^2	0.939	0.947	0.956	0.953	0.918	0.904	0.949	0.955
Panel B: Marginal change in tax base								
Vehicles Lost Exemption (%)	1.24***	0.015***	-2.72***	-0.005***				
	(0.163)	(0.002)	(0.743)	(0.001)				
Vehicles Gained Exemption (%)					0.042	0.000	0.863	0.0005
					(0.100)	(0.001)	(0.741)	(0.001)
Regression statistics								
Mean Dep. Variable	$97.4 BRL	4.51	$599.6 BRL	6.32	$85.7 BRL	4.40	$562.7 BRL	6.25
Observations	1,774	1,774	1,774	1,774	1,260	1,260	1,260	1,260
R^2	0.939	0.947	0.956	0.953	0.918	0.904	0.948	0.955

Notes: This table presents estimates of the effects of changes in the exemption age on municipal *IPVA* revenue per vehicle and public healthcare expenditures per capita, using a difference-in-differences (DiD) design. Analysis of the "Raised Age" treatment is done within the 2013-2018 time-frame due to a policy reversal in GO taking effect in 2019. Study of the "Lowered Age" treatment uses all years from 2013 to 2020. All states in "Raised Age" treatment change policy in 2015, while "Lowered Age" treatment enacts change in 2017, with policies taking effect in following year. Municipal *IPVA* Revenue "Level" coefficients in columns (1) and (5) need to be re-scaled by 2 to be interpreted as total state-level effects as *IPVA* revenue is split equally between local and state governments; this does not impact the "Log" results in columns (2) and (6). 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. Regressions include control for *IPVA* tax rate, present and past year GDP per capita, state gasoline prices (excluding own locality), share fire area, presence of mining, basic VAT rate, and second degree polynomial of weather variables (atmospheric pressure, temperature, precipitation, and wind speed). Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Online Appendix to "Rust in Motion: The Political Environmental Trap of Vehicle Tax Exemptions"

Gabriel Monteiro and Edson Severnini

August 2026

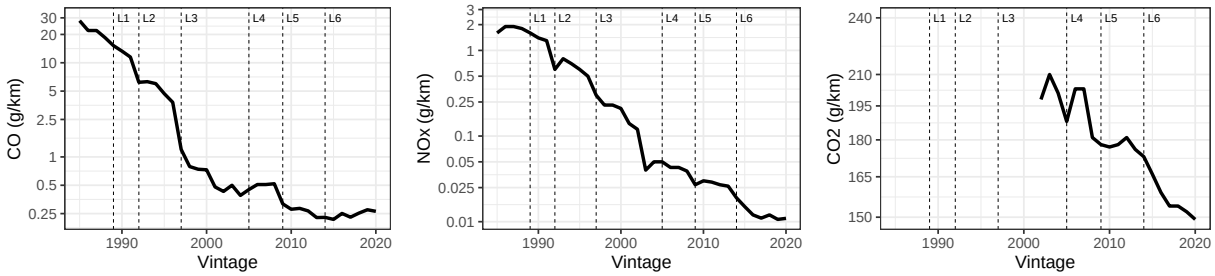
A Institutional Background Appendix

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.

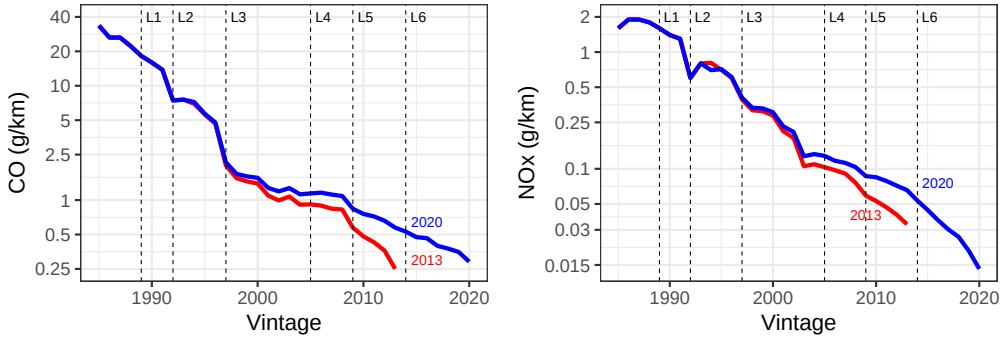
Figure A.1: CETESB – New Gasoline-Powered Light-Duty Vehicles Emissions



(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 Conceptual Framework Appendix

In this Section, we detail a specific model of the households' decision on vehicle replacement.

Building on the initial set-up of the household behavior laid out in Section 3, we assume that the choice-specific idiosyncratic shocks $\varepsilon_a^k, \varepsilon_a^r$ follow independent Type-I Extreme Value distributions with scale parameter $\sigma > 0$.

For brevity, we denote the deterministic parts of the individual's utility for each option as:

$$\begin{aligned} v_k(a) &= -c(a) - T(a;\bar{a}) + \beta W(a+1;\bar{a}) \\ v_r &= -K + \beta W(0;\bar{a}). \end{aligned}$$

From properties of the Type-I EV distribution, the value function $W(a;\bar{a})$ follows a closed form:

$$W(a;\bar{a}) = \sigma \log\left(e^{v_k(a)/\sigma} + e^{v_r/\sigma}\right) + \sigma\gamma,$$

where $\gamma = 0.577$ is the Euler-Mascheroni constant.

Accordingly, the replacement hazard function $p(a;\bar{a})$ follows from a logistic distribution:

$$p(a;\bar{a}) = P\left(\varepsilon_a^k - \varepsilon_a^r < v_r - v_k(a)\right) = \frac{e^{v_r/\sigma}}{e^{v_k(a)/\sigma} + e^{v_r/\sigma}}.$$

As $\sigma \to 0$, the probability approximates a deterministic rule; and it approaches a coin-flip as $\sigma \to \infty$.

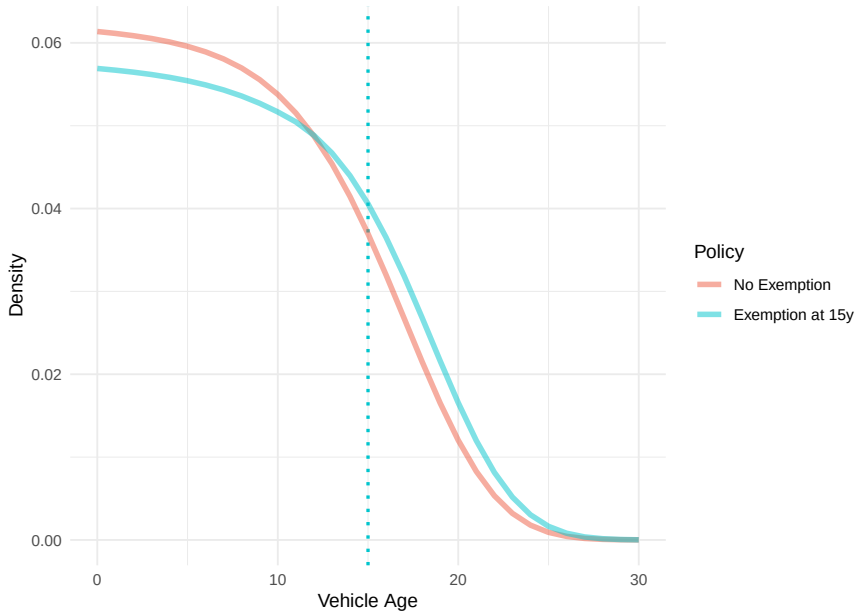
The stationary distribution then follows by applying the closed-form probabilities just described on the density functions:

$$\begin{aligned} f(a+1;\bar{a}) &= (1 - p(a;\bar{a}))f(a;\bar{a}), \\ f(0;\bar{a}) &= \sum_a p(a;\bar{a})f(a;\bar{a}). \end{aligned}$$

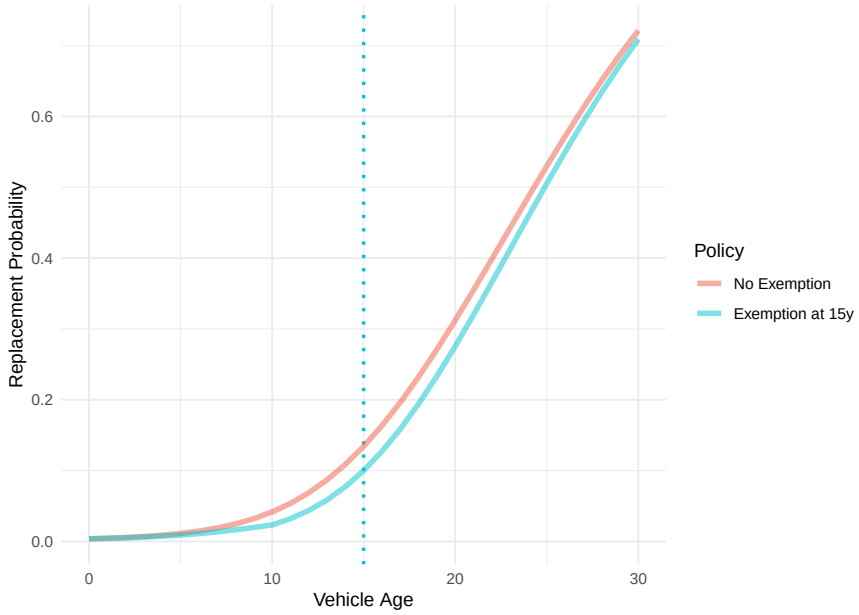
The household problem can be solved using a nested-fixed point algorithm *à la* Rust (1987).

For illustration, we show the output of numerical examples using Type-I EV-distributed shocks under two policies: "No exemption" ($\bar{a} = \infty$) and "Exemption at 15 years" ($\bar{a} = 15$) in Appendix Table B.1.

Figure B.1: Illustration of Fleet Age Distribution and Replacement Probabilities Within the Model



(a) Fleet Age Distribution: $f(a; \bar{a})$



(b) Replacement Probability: $p(a; \bar{a})$

Notes: Panels (a) and (b) illustrate the vehicle age density and replacement probabilities from numerical examples our model under two policies: i) in orange, "No exemption" ($\bar{a} = \infty$); and ii) in light blue, "Exemption at 15 years" ($\bar{a} = 15$). Panel (a) shows that the fleet under a low-age exemption policy presents a slower decline in vehicle age density and and an excess-mass just before and after the threshold relative to a fleet under a no-exemption policy. Panel (b) shows there is generally lower probability of replacement for the economy with the 15-year exemption, and the gap in replacement probabilities relative to the no-exemption economy widens in the region around the threshold.

C Data Appendix

C.1 Vehicle Data

C.1.1 RENAVAM—National Registry of Motor Vehicles

Our vehicle fleet data is based on a publicly available aggregation of Brazil's National Registry of Motor Vehicles (*RENAVAM*), published by the Ministry of Transport. Every new vehicle sold in the country is registered in the *RENAVAM* system with an identification number issued through the state's Department of Transit. This identification number is then used to track the history of the vehicle: changes of ownership, changes in the registered residence of the owner, and formal scrappage. The states' Departments of Transit follow common national guidelines and act under the supervision of the Ministry of Transport. The information gathered locally by each state is fed to the National Registry.

A limitation of this dataset is absence of information on vehicle utilization intensity. *RENAVAM* treats all registered vehicles equally, regardless of being actively in circulation or effectively out-of-use but not formally scrapped. In fact, estimates of the circulating fleet based on tax and mandatory insurance non-compliance are substantially smaller than the total registered fleet (IBPT, 2019): for instance, in 2013, it was estimated to be 27% smaller. One such case of failure of *RENAVAM* in capturing in-use fleet would be informal scrappage, whereby a vehicle is taken out of circulation without reporting the state's Department of Transit. Failure to remove informally scrapped vehicles from the National Registry can lead to an overestimation of the size of fleet cohorts as they age. This concern is mitigated by our border-pair research design, since registration rules and supervision are uniform across state borders. Unless border-adjacent municipalities in different states systematically differ in rates of unreported scrappage, differences in the observed vehicle age distribution should primarily reflect policy variation rather than measurement error differentials.

C.2 Pollution Data

C.2.1 MERRA-2 v. Van Donkelaar $PM_{2.5}$ Measurements

We utilize in our main analysis $PM_{2.5}$ concentration data derived from MERRA-2 (Gelaro et al., 2017). Estimates of fine particulate matter from Van Donkelaar et al. (2021) were also considered but found to be less suitable for our context. Unlike MERRA-2, Van Donkelaar et al. (2021) apply a geographically weighted regression to calibrate satellite-based estimates using ground monitors. However, monitoring coverage in Brazil is quite sparse, concentrated in a few metropolitan areas, and highly uneven across states. This raises concerns about measurement error that may correlate with state borders, which is particularly problematic given our identification strategy. Within the context of the border-pair approach, we compare MERRA-2 and Van Donkelaar measures of $PM_{2.5}$ in Appendix Table C.1 and find that MERRA-2 correlates more strongly with variables associated with local air pollution. Meanwhile, Van Donkelaar measures are positively correlated with presence of ground monitors in a state.

C.2.2 Ground Monitor Coverage

The use of ground-based monitoring is not feasible for a nationwide analysis in our context due to very limited coverage. As in many developing countries, ground-based air pollution monitoring in Brazil remains highly limited, with roughly 40% states lacking any monitoring infrastructure as recently as 2023.[1] The case of PM2.5 ground-monitoring is even starker, with monitoring in only 4 out of 27 states as late as 2020, and concentrated in a small number of metropolitan areas according to data collected by IEMA (Institute of Energy and Environment).[2]

[1]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.

[2]See https://energiaeambiente.org.br/qualidadedoar/.

C.2.3 Tables

Table C.1: MERRA-2 v. Van Donkelaar $PM_{2.5}$ measurements within border-pairs: partial correlations with stationary pollution sources and pollution monitoring

	Log $PM_{2.5}$	
Dependent Variables:	MERRA	Van Donkelaar
Model:	(1)	(2)
Group of Variables A: Stationary Pollution Sources		
Fossil Fuel Plant	0.02	-0.01
	(0.01)	(0.01)
Biomass Plant	0.05**	0.01
	(0.02)	(0.02)
Share of Fire Area	0.94**	0.07
	(0.40)	(0.29)
Highway Presence	-0.01	-0.10***
	(0.03)	(0.03)
Mining Presence	-0.03*	0.05***
	(0.02)	(0.01)
Group of Variables B: Pollution Monitoring		
$PM_{2.5}$ Monitor in State	0.01	0.07***
	(0.04)	(0.02)
Fixed-effects		
Year-Border-Layer Pair	Yes	Yes
Fit statistics		
Observations	19,357	19,357
R^2	0.850	0.933
Within R^2	0.071	0.088

Notes: This table compares the partial correlation of various stationary pollution sources and of presence of $PM_{2.5}$ monitoring station in the state to MERRA and Van Donkelaar $PM_{2.5}$ measurements of $PM_{2.5}$ concentration. Each column presents the results from a single regression of the $PM_{2.5}$ measurement on the displayed variables. Covariates are distinguished between groups for easier interpretation: i) group A are known stationary pollution sources which are expected to be positively correlated with $PM_{2.5}$, ii) group B includes an indicator variable for presence of $PM_{2.5}$ pollution monitoring in the state. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include Year-Border-Layer Pair fixed effects, five region dummies and control for latitude and longitude with quadratic polynomials—the same specification used in the cross-border balancing check in Appendix Table D.1. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

C.3 Election Data

C.3.1 Institutional Information on Data

The electoral process and laws in Brazil are established and supervised at the federal level, including for subnational offices. State elections for the executive and legislative branches are held statewide and occur simultaneously across all states on a fixed four-year cycle, coinciding with federal elections. Executive elections may require two rounds: if no candidate obtains a majority of valid votes in the first round, a runoff is held between the two leading candidates three weeks later. The candidate that consolidates a majority of votes in either the first or the second round—if triggered—is elected. Legislative elections are conducted in a single round. Governors are limited to two consecutive terms, while members of the state legislature are not subject to term limits.

C.4 Municipal *IPVA* Tax Revenue and Healthcare Expenditures

C.4.1 Institutional Information on Data

The country's public healthcare funding is constitutionally shared between local, state, and federal levels (Article 198, Brazil's 1988 Constitution). Municipalities' responsibilities are centered on primary care delivery, such as providing management and resources to "family-health" services (*Programa Saúde da Família*) and basic-health units (*Unidades Básicas de Saúde*).[3] Local government health expenditures respond to supply and demand forces, but are bounded by institutional elements: no less than 15% of municipalities' revenue must be directed to public health actions and services (Constitutional Amendment 29/2000). This implies that revenue-increasing reforms lift the health expenditure floor mechanically.

C.5 Additional Data

We collect data on a range of factors that could potentially confound our estimates. Below we briefly describe each data source and the procedures used to incorporate them into our analysis.

Climate/Weather: Climate conditions and weather shocks may affect both pollution measurement and local economic activity. We obtain climate data from the dataset compiled by Saldanha et al. (2024), which provides daily municipality-level records of temperature, precipitation, atmospheric pressure, and U- and V-wind components from 1950 to 2023. The

[3]See Paim et al. (2011) for institutional and historical background. Further detail in institutional organization laid out by the Ministry of Health in *Portaria MS/GM nº 2.488, de 21 de Outubro de 2011.*

dataset is constructed by aggregating hourly gridded data from ERA5-Land (Hersbach et al., 2020). We aggregate all variables to the municipality-year level.

Value Added Tax and Fuel Prices: States' primary own-source revenue is the *ICMS*, a value-added tax with heterogeneous rates across products and services. Given its potential relevance as a policy confounder, we control for both baseline tax rates and fuel prices in our analysis. We collect data on each state's baseline *ICMS* rate from 2013 to 2020 using changes in state legislation. To capture fuel-specific tax variation, we obtain gasoline price data from the *Agência Nacional do Petróleo* (ANP). We compute annual inflation-adjusted gasoline prices at the state level, excluding the contribution of the municipality itself.[4]

Presence of polluting activities: To account for the potential confounding effect of the location of pollution-intensive activities, we collect data on fossil fuel and biomass thermal power plants, fire-affected areas, and mining sites. All data are drawn from MapBiomas, a collaborative network of NGOs, universities, and technology firms that compiles information on land cover, land use, and natural resource management in Brazil (Souza et al., 2020). For fossil fuel and biomass thermal power plants, we use a cross-sectional dataset of all facilities as of August 2022 and assign their locations to all years in the sample. For fire activity, we use annual maps of burned areas to compute the share of each municipality affected by fires each year. For mining activity, we use longitudinal data on mining areas at the municipality-year level and construct an indicator for whether mining activity is present.

Population, GDP, and Highways: Municipal GDP data are obtained from the *Base dos Dados* platform, which compiles official statistics from the Brazilian Institute of Geography and Statistics (IBGE).[5] Population data for 2010 are drawn from the 2010 Population Census through IPEADATA, a data platform maintained by the Institute of Applied Economic Research (IPEA). We compute municipal GDP per capita by dividing the total GDP by the 2010 population. In addition, to account for differences in traffic exposure associated with transportation infrastructure, we obtain spatial data on all state and interstate highways from the World Bank.[6] We construct an indicator for whether a municipality is intersected by a highway.

[4]Let municipality m be in state S at year t. We construct a "leave-one-out" state-year average as $g_{-m,S,t} = \frac{1}{N-1}\sum_{i \in S} g_{i,S,t}$, where $g_{i,S,t}$ denotes the municipality-year gasoline price. For the Federal District, which consists of a single municipality, we use the observed municipality value as the state average.

[5]Municipal GDP from *Base dos Dados* is available at: https://basedosdados.org/dataset/fcf025ca-8b19-4131-8e2d-5ddb12492347.

[6]Maps of Brazilian highways are available at: https://datacatalog.worldbank.org/search/dataset/0038536.

C.6 Summary Statistics

Table C.2: Summary Statistics: All Municipalities vs. Layers 1-2 (Main Sample), 2013-2020

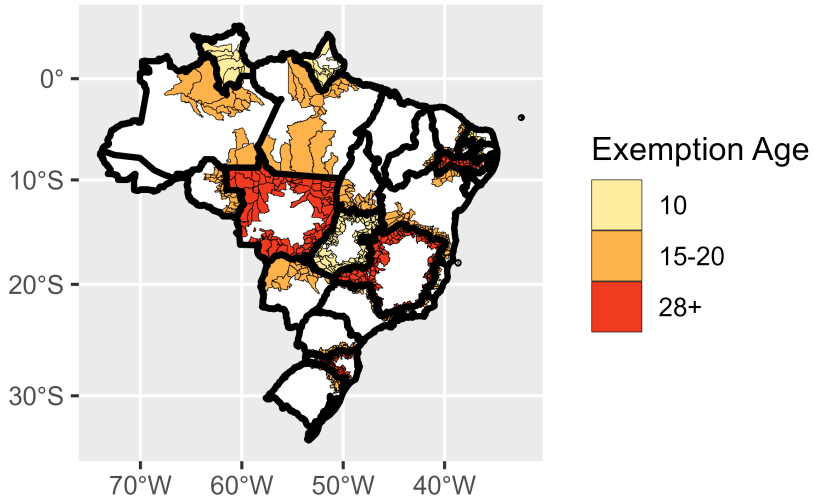
	(1) All	(2) Layers 1-2	(3) Not in Layers	(4) (2) - (3)
Panel A: General Characteristics				
2010 Population (by 1,000)	34.28	24.51	41.84	-17.33* (7.59)
GDP per capita (1,000 BRL)	15.61	14.32	16.61	-2.29 (1.58)
Centroid Distance to Border (Miles)	58.35	26.20	83.24	-57.03*** (4.58)
Area in 1,000 km^2	1.62	2.48	0.95	1.53*** (0.57)
Panel B: Fleet				
Average Vehicle Age	13.39	12.59	14.01	-1.42*** (0.43)
Vehicles 0-10 (%)	51.58	54.73	49.15	5.58*** (1.59)
Vehicles 11+ (%)	48.42	45.27	50.85	-5.58*** (1.59)
Vehicles 11-20 (%)	26.61	26.11	26.99	-0.88** (0.38)
Vehicles 21+ (%)	21.81	19.16	23.86	-4.70*** (1.41)
Vehicles per capita	0.41	0.36	0.44	-0.07** (0.03)
Fleet Size (by 1,000)	17.05	10.97	21.76	-10.79** (4.88)
Panel C: Pollution				
$PM_{2.5}$ Concentration ($\mu g/m^3$)	7.59	7.46	7.69	-0.22 (0.37)
CO Concentration ($ppbv$)	114.51	107.23	120.15	-12.93 (8.05)
$CO2$ On-road Emissions ($1,000t$)	31.98	24.93	37.45	-12.51** (6.03)
NOx On-road Emissions (t)	184.08	150.97	209.71	-58.74* (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 (0.03)
Fossil Fuel Power Plant	0.13	0.12	0.14	-0.03 (0.02)
Biomass Power Plant	0.08	0.09	0.08	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	9.38	9.39	-0.01 (0.01)
Low Birth Weight (per 1,000)	80.03	76.97	82.40	-5.44*** (1.61)
Very Low Birth Weight (per 1,000)	12.15	11.59	12.59	-1.00*** (0.28)
28-Day Infant Mortality (per 1,000)	7.81	8.00	7.67	0.33* (0.19)
Healthcare Facility	0.55	0.56	0.53	0.03 (0.03)
Health Facilities Beds	90.71	58.19	115.89	-57.70*** (20.20)

Notes: This table presents a summary of statistics of key variables in our analysis for the following samples: all municipalities, Layers 1 and 2 (Main Sample), and municipalities excluded from Layers 1 and 2. In column (4) we present the differences between municipalities inside and outside of Layers 1 and 2. Clustered State-level standard-errors in parenthesis. Municipalities are equally weighted in all regressions. Monetary values were adjusted by inflation to 2010 prices.

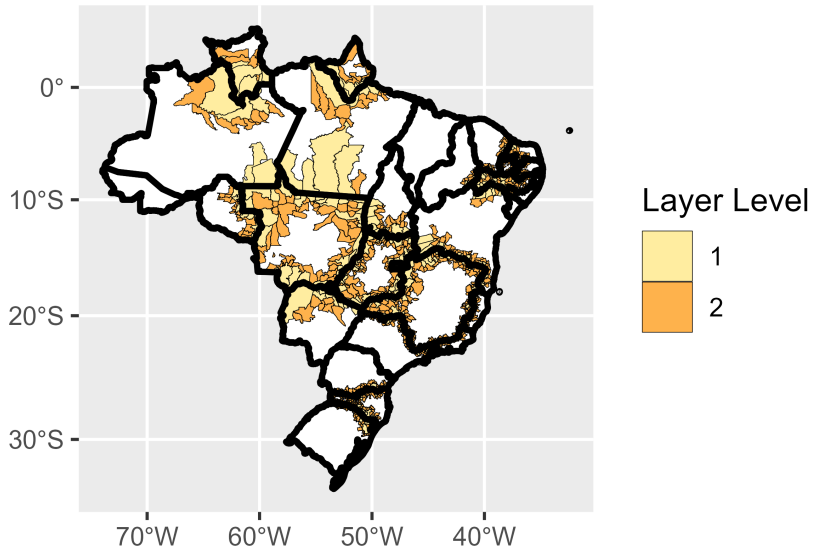
D Border-Pair Approach Appendix

D.1 Identification

Figure D.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.

D.2 Characteristics across borders

Table D.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	Has Highway
Exemption Age: 10	0.15	-0.02	-0.07*	-919.78	0.00
	(0.15)	(0.04)	(0.04)	(607.81)	(0.00)
Exemption Age: 15-20	0.04	-0.01	0.00	-35.17	0.00
	(0.11)	(0.03)	(0.04)	(97.34)	(0.00)
Regression Statistics					
Observations	19,357	19,357	19,357	19,357	19,357
R^2	0.784	0.876	0.133	0.702	0.136
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.586	0.911	0.007	0.270	0.554
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	-0.23	-0.74	-0.20**	-0.17	0.01**
	(0.31)	(0.50)	(0.10)	(0.10)	(0.00)
Exemption Age: 15-20	0.05	0.04	-0.11***	-0.03	0.00
	(0.04)	(0.17)	(0.04)	(0.03)	(0.00)
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
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.398	0.296	0.004	0.184	0.033
Panel C: Geography and Weather					
Dependent Variables:	Distance to Border	Muni Area 1,000km^2	Avg. Temperature	Wind Speed	Precipitation
Exemption Age: 10	-10.16**	-2.89	0.47**	0.01	-0.11**
	(3.94)	(2.09)	(0.21)	(0.06)	(0.04)
Exemption Age: 15-20	-0.14	0.59	0.38*	0.00	-0.06
	(1.51)	(0.68)	(0.22)	(0.04)	(0.03)
Regression Statistics					
Observations	19,357	19,357	19,357	19,357	19,357
R^2	0.726	0.587	0.909	0.863	0.916
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.010	0.027	0.047	0.981	0.036

Notes: This table presents a 'balancing-check' comparing the characteristics of near-border municipalities under low exemption ages to municipalities under *de facto* no-exemption policy. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include Year-Border-Layer Pair fixed effects, five region dummies, and control for latitude and longitude with quadratic polynomials. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

E Main Results Appendix

E.1 Fleet Characteristics

Table E.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	0.02	-0.01	0.03**	0.01*	0.02***
	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)
Exemption Age: 15-20	-0.01	-0.02*	0.01	0.00	0.01**
	(0.02)	(0.01)	(0.01)	(0.01)	(0.00)
Regression Statistics					
Mean Dep. Variable:	0.45	0.24	0.21	0.12	0.09
Observations	19,357	19,357	19,357	19,357	19,357
R^2	0.815	0.756	0.859	0.800	0.876
Panel B: Vehicle age percentile					
Dependent Variables:	Percentile 10	Percentile 30	Median	Percentile 70	Percentile 90
Exemption Age: 10	0.27***	0.71***	1.33***	1.81***	1.01*
	(0.09)	(0.15)	(0.25)	(0.38)	(0.56)
Exemption Age: 15-20	0.07	0.22**	0.49***	0.66**	0.63*
	(0.05)	(0.09)	(0.17)	(0.26)	(0.33)
Regression Statistics					
Mean Dep. Variable:	1.83	5.27	8.80	14.42	25.75
Observations	19,357	19,357	19,357	19,357	19,357
R^2	0.803	0.856	0.805	0.831	0.861

Notes: This table presents auxiliary evidence to understand the effect of low exemption age policies on the age distribution of the vehicle fleet. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

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

Model:	(1)	(2)	(3)	(4)
Panel A: Δ Vehicles in Vintage Group				
Dependent Variables:	1 year	1-10 years	11-20 years	21+ years
Exemption Age: 10	-889.08*	406.01	582.81**	34.76
	(464.76)	(246.21)	(276.30)	(29.58)
Exemption Age: 15-20	-61.19	-47.26	143.12***	22.91
	(84.77)	(117.48)	(51.97)	(18.92)
Regression Statistics				
Mean Dep. Variable:	1,534.97	385.16	-438.68	-64.16
Observations	16,941	16,941	16,941	16,941
R^2	0.983	0.731	0.957	0.782
Panel B: Δ% Vehicles in Vintage Group				
Dependent Variables:	1 year	1-10 years	11-20 years	21+ years
Exemption Age: 10	-4.08***	1.79***	1.46***	0.83***
	(1.43)	(0.47)	(0.40)	(0.26)
Exemption Age: 15-20	-0.20	0.77**	0.73***	0.38**
	(1.30)	(0.36)	(0.20)	(0.19)
Regression Statistics				
Mean Dep. Variable:	28.54	3.48	1.01	0.64
Observations	16,930	16,941	16,940	16,905
R^2	0.215	0.464	0.415	0.222

Notes: This table presents auxiliary evidence to understand how the dynamics of fleet retainment and renewal are impacted by age-based exemption policies. 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. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

E.2 Infant Health

Table E.3: Poisson Regression: Policy Impacts on Infant Health

	(1)	(2)	(3)	(4)
Dependent Variables:	Average 5-min Apgar	Low Birth Weight	Very Low Birth Weight	28 Days Infant Mortality
Exemption Age: 10	-0.02***	0.10***	0.22***	0.08*
	(0.01)	(0.02)	(0.04)	(0.05)
Exemption Age: 15-20	-0.01**	0.03**	0.02	0.01
	(0.00)	(0.01)	(0.02)	(0.02)
Regression Statistics				
Observations	19,357	19,357	19,357	19,357
F-Test: $\beta_{10} = \beta_{15-20}$ (p-value)	0.019	0.000	0.000	0.106

Notes: This table presents the analogous analysis from Table 1, Panel C, but utilizing a Poisson regression approach. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

F Robustness

F.1 Main Robustness Exercises

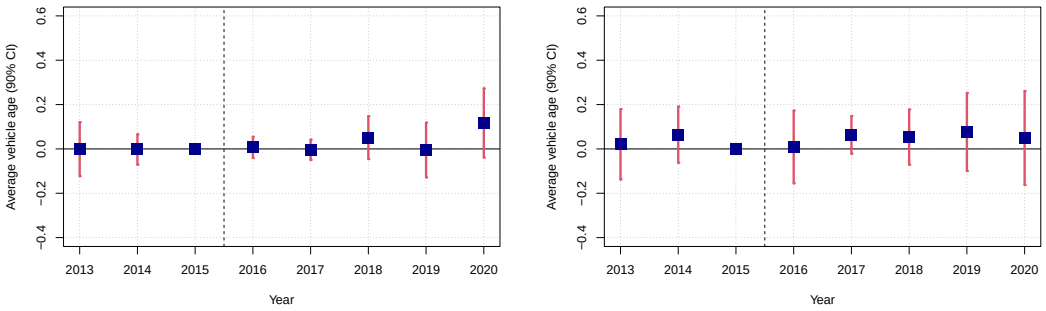
Table F.1: Heterogeneous Policy Impacts by Wind Direction and Wind Speed

Dependent Variables:	Log PM2.5	Log CO	Log PM2.5	Log CO	Log PM2.5	Log CO
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Exemption Age: 10	0.04**	0.07**	0.04**	0.08**	0.04*	0.07**
	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
Exemption Age: 15-20	0.04***	0.08***	0.04***	0.09***	0.06***	0.11***
	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.03)
Exemption Age: 10 × Wind Direction No/High → Low	-0.07**	0.04				
	(0.03)	(0.06)				
Exemption Age: 15-20 × Wind Direction No/High → Low	-0.02	-0.02				
	(0.02)	(0.04)				
Exemption Age: 10 × Wind Direction Low → No/High			-0.05*	-0.05		
			(0.03)	(0.04)		
Exemption Age: 15-20 × Wind Direction Low → No/High			0.00	-0.05		
			(0.02)	(0.03)		
Exemption Age: 10 × Wind Speed Above Median					-0.01	-0.04
					(0.03)	(0.03)
Exemption Age: 15-20 × Wind Speed Above Median					-0.04**	-0.08**
					(0.02)	(0.04)
Regression statistics						
Observations	19,357	19,357	19,357	19,357	19,357	19,357
R^2	0.936	0.839	0.936	0.839	0.936	0.841

Notes: This table tests whether the estimates of effects of exemption policies on pollutant concentration were driven by cross-border wind-transported pollution by exploring wind direction and speed heterogeneity within our border-pair study. These exercises are implemented by interacting the exemption age indicators with indicators for: i) wind wind flows from no/high exemption to low exemption age side in columns (1) and (2); ii) wind flows from low to no/high exemption side in columns (3) and (4); and iii) wind speed is above sample median in columns (5) and (6). Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

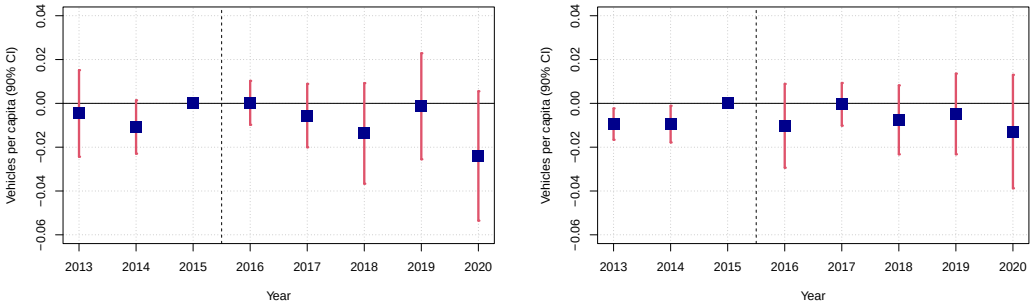
Figure F.1: Spillover Event-Study: What Happens when a Neighbor State with Same Exemption Age Changes Policy? Comparing Layers 1 and 2 in States Keeping Status Quo

(a) Panel A: Average Vehicle Age



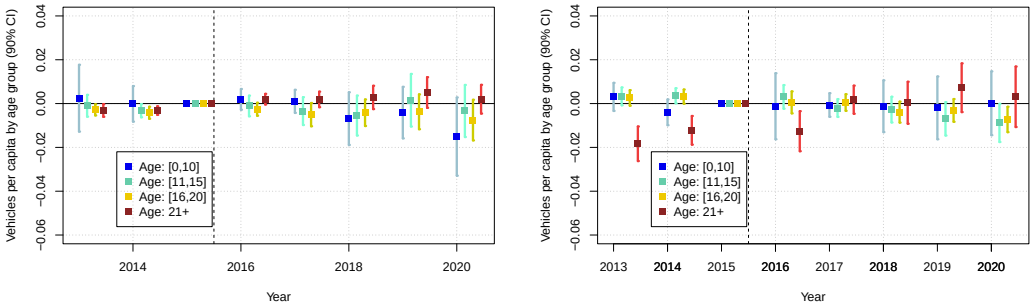
Status Quo Neighbor to TO (15 → No) Status Quo Neighbor to MS (15 → 20)

(b) Panel B: Vehicles per capita



Status Quo Neighbor to TO (15 → No) Status Quo Neighbor to MS (15 → 20)

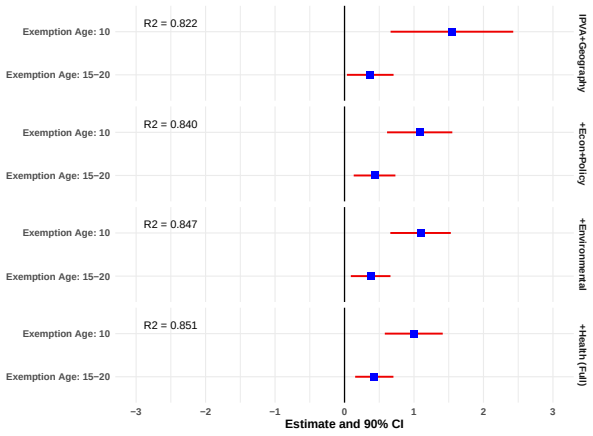
(c) Panel C: Vehicles per capita by age group



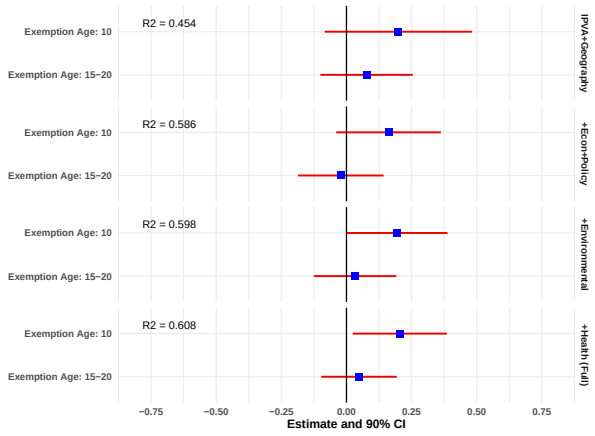
Status Quo Neighbor to TO (15 → No) Status Quo Neighbor to MS (15 → 20)

Notes: This figure tests presence of non-negligible spillover effects from exemption policies on the fleets of neighboring municipalities using a DiD event-study design. This exercise is implemented by estimating via OLS the following Equation: $y_{m,t} = \sum_{j \neq 0} \psi_{g,j} \mathbf{1}\{t - T_g = j\} Spill_m + X'_{m,t}\vartheta + \eta_m + \delta_t + \upsilon_{m,t}$, with $\psi_{g,j}$ representing the parameters of interest. Layer 1 municipalities are categorized as "spillover treated" and we use layer 2 as the "control" group. The sample for the analysis of the status quo neighbors to TO contains 480 municipality-year observations from the following states: BA, MA, PA, and PI. The sample for the analysis of the status quo neighbors to MS is comprised 168 municipality-year observations from the state of PR. Squares represent the point-estimates, and thin lines represent 90% 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 and within-state and time- varying controls described in the methodology subsection.

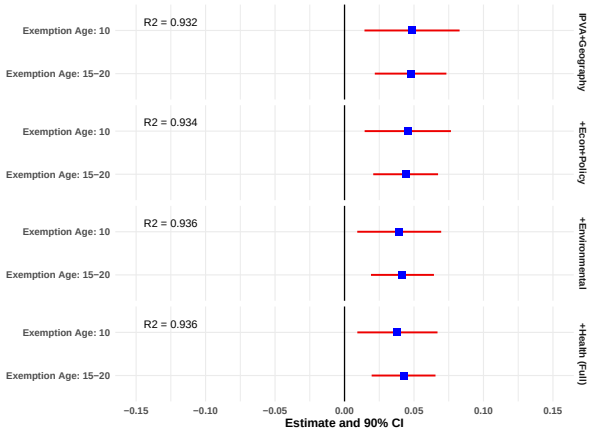
Figure F.2: Coefficients stability to different specifications



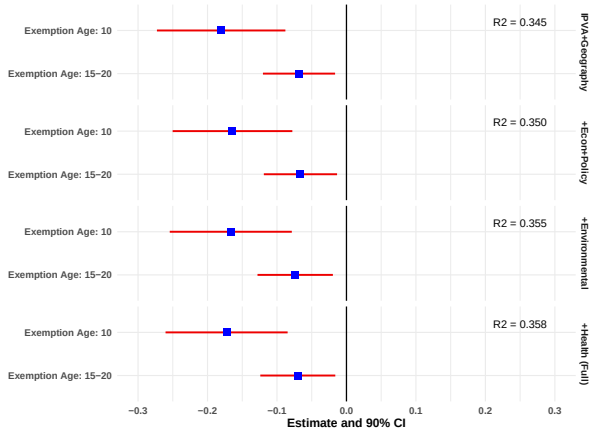
(a) Average Vehicle Age



(b) Log NOx Emissions per capita (Road)



(c) Log $PM_{2.5}$ Concentration



(d) Average 5-min Apgar Score

Notes: This figure reports the estimates of the effect of low exemption age thresholds across a series of specification that progressively add control variables. We present the coefficients of 1{Exemption: 10y} and 1{Exemption: 15-20y}. Blue dots represent the point-estimates, and red lines are the 90% confidence intervals. Errors are clustered at the state-border level. Observations are at the municipality-year level, and are weighted by the 2010 population. All specifications include year-state-layer pairs fixed effects and controls for IPVA tax rates for different vehicle categories and for geographical characteristics. Groups of control variables are added at each step as indicated in figures. Groups of variables are described in the Section 5.

F.2 Additional Robustness Tests and Results

Table F.2: Other Pollutants and Infant Health Variables

	Pollutants - MERRA-2		1-Min Apgar	Weight at Birth			
	Log O3 (Concentration)	Log CO (Emissions)		All	White Mother	Non-White Mother	Black Mother
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Exemption Age: 10	0.0005**	0.1656*	-0.07	-25.7***	-34.8***	-25.1***	-68.3***
	(0.0002)	(0.0922)	(0.06)	(7.8)	(13.2)	(8.5)	(20.8)
Exemption Age: 15-20	0.0005***	0.2574***	-0.05**	-6.1	-9.7	-10.2**	-12.8
	(0.0002)	(0.0740)	(0.02)	(4.9)	(8.7)	(5.1)	(8.0)
Regression statistics							
Mean Dep. Variable:	5.56	-21.73	8.32	3,194 (g)	3,187 (g)	3,188 (g)	3,171 (g)
Observations	19,357	19,357	19,357	19,357	19,108	19,233	15,798
R^2	0.989	0.600	0.327	0.474	0.166	0.268	0.106
Exemption 10 = 15-20 (p)	0.946	0.098	0.764	0.001	0.018	0.024	0.002

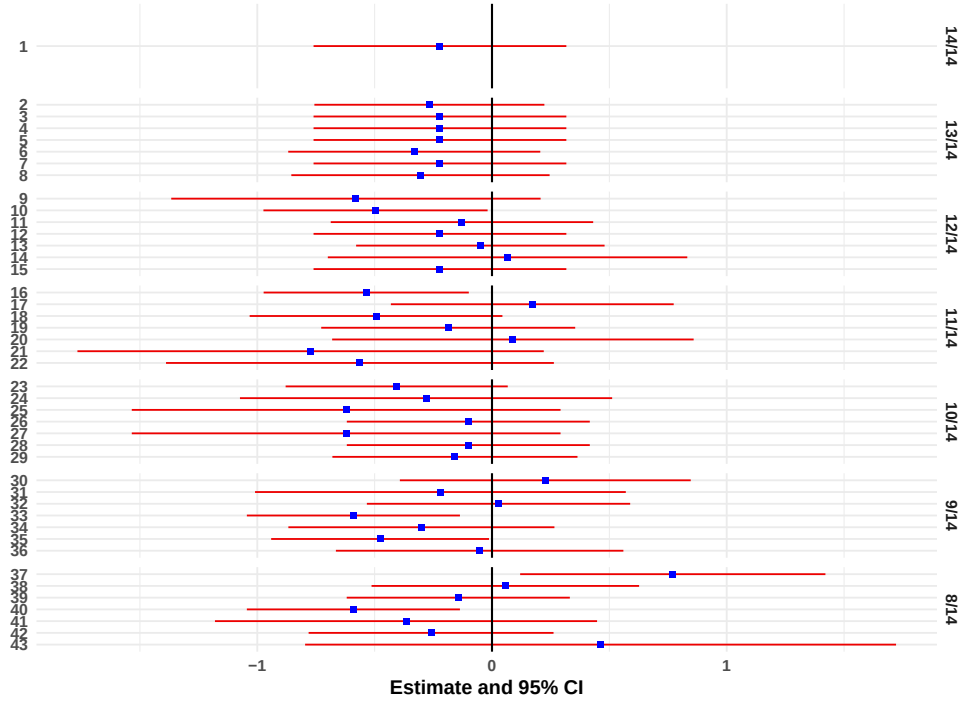
Notes: This table presents estimates of the effects of low exemption age thresholds on alternative measures of pollution and infant health. Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Table F.3: Only Layer 1 Municipalities: Policy Impacts on Fleet, Emissions, and Infant Health

	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	0.80**	0.04	0.46***	0.47***	-0.14*	6.05***
	(0.31)	(0.03)	(0.13)	(0.12)	(0.08)	(1.79)
Exemption Age: 15-20	0.38*	-0.02	0.13*	0.18**	-0.06	2.21
	(0.20)	(0.02)	(0.07)	(0.08)	(0.04)	(1.39)
Regression statistics						
Observations	9,256	9,256	9,066	9,066	9,256	9,256
R^2	0.854	0.801	0.637	0.633	0.384	0.278

Notes: Standard-errors in parentheses are clustered at the state-border level. Observations are weighted according to the 2010 municipal population. All regressions include our full set of controls. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Figure F.3: Placebo Treatment on Average Vehicle Age: State-Border Pairs in Same Exemption Age Groups, Only Pairs With No Policy Change



Notes: Sample is comprised of 14 state-border pairs in which neither state changed exemption age during analysis, and where both sides are in the same exemption age group. Each row represents a different placebo exercise (left-side numbering), which are grouped (right-side label) according to the likelihood the pair is assigned for placebo difference – i.e. one side to be "placebo treated". When this happens, the side with lower state code is assigned to receive "placebo treatment". Blue dots represent the point-estimates, and red lines are the 95% confidence intervals based on standard-errors clustered at state-border level. All regressions includes 2010 municipal population weights. All regressions include our full set of controls.

F.3 RD

We provide an alternative analysis using a Regression in Discontinuity design, by leveraging the sharp change in policy at state border, with a running variable based on the distance between municipality centroid and the state border. We propose this approach as a robustness exercise and consider it less appropriate as a research design than our main border-pair approach. The regular RD design assigns all information of the municipality (our unit of analysis) to a single point in the running variable line, and bandwidths are defined to limit the sample to some region of this line. However, with a running variable based on the border-centroid distance, the ordering of observations is based simply on the size (and shape) of the municipality (and of their neighbors in the path to the border if the municipality does not touch the border). Since sample selection depends on the running variable value position relative to the bandwidth, selection is mostly based on how small are the municipalities (and their neighbors). Worse, since RD relies on the functional form between outcome and running variable, local polynomials will depend heavily on the ordering of municipality sizes. In contrast, the border-pair approach lets us abstract from sizes and shapes of municipalities, and compare groups directly.

F.3.1 Methodology

We construct a running variable based on the distance between the municipality's centroid and the state border, and on which side has higher exemption age, such that:

$$R_m = \begin{cases} Dist.Border_m \text{ , if } Exemption(S(m)) < Exemption(S'(m)) \\ -Dist.Border_m \text{ , if } Exemption(S(m)) > Exemption(S'(m)). \end{cases}$$

That is, the running variable assumes positive values when it pertains to a municipality that is a lower exemption age bin than its state-pair – $Exemption(S(m)) < Exemption(S'(m))$ –, and negative values when that municipality is on the side of the border with a higher exemption age bin – $Exemption(S(m)) > Exemption(S'(m))$. For the RD analysis, we explicitly only consider cases where pairs are in different exemption age groups.

In the RD design, we identify the effects of low vehicle exemption age "right-at-the-border". Explicitly, this is the difference in potential outcomes for a hypothetical (dimensionless) municipality with centroid exactly at the border if they have a low exemption age versus if they have some other baseline policy. Thus, the effect of treatment depends on what policy

comparisons are being made.

$$\begin{aligned} LATE(\kappa, \kappa') &= \lim_{r \downarrow 0^+} E[y_{mt} | R_m = r] - \lim_{r \uparrow 0^-} E[y_{mt} | R_m = r] \\ &= \lim_{r \downarrow 0^+} E[y_{mt} | R_m = r, Exemption = \kappa] \\ &\quad - \lim_{r \uparrow 0^-} E[y_{mt} | R_m = r, Exemption = \kappa']. \end{aligned}$$

The first conditional expectation measures the expected outcome for a municipality "right-at-the-border" under a given low exemption age policy ($Exemption = \kappa$). The second conditional expectation gives the expected outcome for an analogous "at-the-border" municipality under a baseline (higher) exemption age policy ($Exemption = \kappa'$). Under the assumption that the two conditional expectations are continuous in r, the difference captures the effect of a low exemption age (κ) compared to the baseline policy (κ') at the discontinuity.

We operationalize this comparison through local polynomial regressions using only data within a bandwidth h of the border. Formally, for each pair of policy comparisons, we estimate the following model within a bandwidth of the border:

$$y_{mt} = \beta(\kappa, \kappa') \mathbf{1}\{R_m > 0\} + f_0(R_m) + \mathbf{1}\{R_m > 0\} f_1(R_m) + \iota_t + \upsilon_{mt}.$$

The parameter $\beta(\kappa, \kappa')$ captures the difference in potential outcomes between the two policies for a municipality at the border. We rely on the approach developed by Calonico et al. (2014) for optimal bandwidth selection. We employ a triangular kernel, placing more weight on observations closer to the border. We estimate our model under a quadratic specification for the functions f_0 and f_1. Year fixed effects ι_t are used to control for common time trends. Observations are weighted by municipality population. υ_{mt} is the error term.

F.3.2 Results

The results from our RD estimates help support the main findings of higher average vehicle age in states with exemption age between 15 and 20 years compared to states with no exemption, and in states with 10-year exemptions compared to ones with threshold between 15 and 20 years. However, the estimates are noisier and the coefficients are higher in magnitude. We caution against over-analyzing the direct comparisons between localities with "de facto" no exemptions and 10-year exemptions since, within the RD framework, those are based on very small samples.

Point-estimates for the effects on pollution concentration, NOx emissions, and average Apgar

score follow the signs of our main analysis for the relevant comparisons in this framework. Due to the structure of the underlying gridded data of the $PM_{2.5}$ concentration, which are overlayed into municipalities, the differences at the border are biased towards zero since pixels can be shared between neighboring municipalities across state borders.

Table F.4: Border as Discontinuity, CCT Robust Bias-Corrected RDD

	Average Vehicle Age (1)	Log PM 2.5 Concentration (2)	Log NOx Emissions per capita (Road) (3)	Average 5-min Apgar Score (4)
No Exemption v. at 15-20y	1.961	0.048	1.323***	-0.135
	(1.27)	(0.105)	(0.479)	(0.111)
Bandwidth	30.809	27.278	36.615	37.153
Observations	5271	4858	5530	5583
No Exemption v. at 10y	0.052	-0.314	-1.573	-0.234
	(2.695)	(0.192)	(2.339)	(0.508)
Bandwidth	45.119	39.645	47.281	37.564
Observations	294	262	321	267
Exemption at 15-20y v. at 10y	2.038**	0.071	0.538	-0.240
	(0.957)	(0.12)	(0.399)	(0.157)
Bandwidth	75.36	76.085	71.21	46.154
Observations	1800	1741	1657	1439

Notes: Observations are at the municipality-year level and were weighted by their 2010 population measured in the population census. Each estimate is computed with CCT-optimal bandwidth selections (Calonico et al., 2014), using triangular kernel, municipality-level clustering, and controlling for year fixed effects. We utilize robust bias-corrected standard errors. Local polynomials are estimated at each side of cut-offs.

F.4 Difference in Differences: Event-Study

To investigate the dynamic effects of changes in *IPVA* exemption age, we implement three separate event-study analyses, leveraging policy changes during our time-frame. The cases studied are: i) Mato Grosso do Sul (MS) raising exemption threshold from 15 to 20 years, and Tocantins (TO) moving from 15 to no exemption cutoff, both in 2015; ii) Goiás (GO) raising the threshold from 10 to 15 years in 2015 and reverting to 10 years in 2018; and iii) Mato Grosso (MT) introducing an 18-year cutoff from a prior "No exemption" baseline in 2017.

While our main research strategy captures the 'steady-state' or long-run differences between states with different policies, the event-study exercise lets us capture shorter-term effects and evolution of differences that arise from policy choices. On one hand, this exercise provides evidence on how the evolution on state differences can generate the 'steady-state' equilibrium we observe, but some evidence of short-term deviations suggest behavioral mechanism might also be relevant right after policy changes.

F.4.1 Methodology

For each one of our policy-change groups (g) described and each outcome of interest, we estimate the following event-study specification:

$$y_{mt} = \sum_{j \neq 0} \beta_j \mathbf{1}\{t - T_g = j\} Treated_m + X'_{m,t}\vartheta + \eta_m + \delta_t + \upsilon_{m,t},$$

where y_{mt} is a measurement of our outcome of interest in municipality m and year t, and T_g denotes the year of enactment of a policy change for group g – noting that changes take effect the following year. In the case of GO, where there are changes in the exemption age, T_g is the year of the first policy change. The indicator variable $Treated_m$ denotes the municipality m is part of a state that changes the exemption threshold during the period of study. The coefficients β_j capture the average differences in outcomes y_{mt} between treated and untreated groups relative to their own outcomes j periods from the year of policy change, with $k = 0$ being held as omitted reference point. We control for municipality and year fixed effects, η_m and δ_t. X'_{mt} is a vector including time-varying controls, namely: present and past year GDP per capita, state gasoline prices (excluding own municipality), share fire area, presence of mining, basic VAT rate, and second-degree polynomials of weather variables(atmospheric pressure, temperature, precipitation, wind speed). υ_{mt} is a municipality-year error term.

The sample for this analysis is comprised of matched border-layer pairs. This means one border-pair is in the "treated" group, i.e. municipalities from a state that changes the exemption threshold, and the "comparison" group is comprised of matched border-pairs that does not change policy. Due to more limited sample size in each analysis, we increase our sample selection from two to three layers to increase power.

F.4.2 Results

In Figure F.4, we present the event-study graphs for each policy change group for three outcomes: average vehicle age, vehicles per capita, vehicles per capita by age group, and (log) *IPVA* revenue per capita.

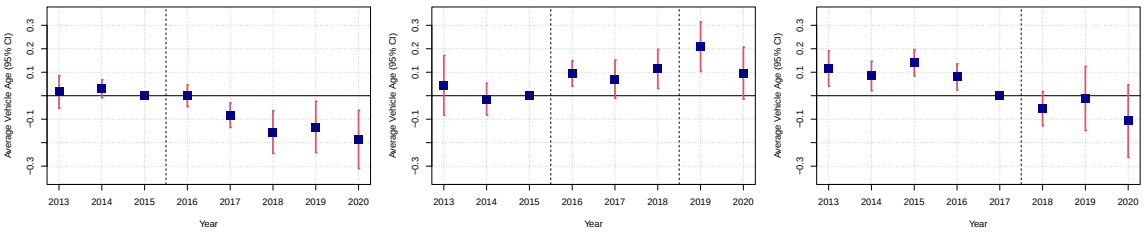
Focusing first on the pooled case of the increase in the exemption age cutoff in MS and TO, we see that the average vehicle age in these states falls relative to its baseline trend, being around 0.2 year lower five years after policy change than its counterfactual. Changes in the number of vehicles per capita do not show significant deviations from the expected had the exemption age stayed the same. *IPVA* revenue raised by municipalities also increases significantly relative to baseline after 2015.

In the case of GO, there are two policy changes. When the age cutoff is increased from 10 to 15 years, we observe a relative increase in the average vehicle age of 0.1 year just after the policy change. This contrasts with the findings from the pooled MS and TO event-study and the "steady-state" differences across states found in the main analysis which would suggest a decline in age. A potential hypothesis is that, besides the usual mechanism of scrappage decision based on current and expected costs of ownership of vehicle, some owners might also have behavioral biases pushing them to avoid scrapping vehicle before the exemption threshold when it is close enough. Posterior to the policy reversal, average vehicle age sits in a similar level within two years despite very-short-term variation. In terms of the number of vehicles per capita, we observe negative variations in the trend relative to the baseline right after each policy change, but those are reverted in a short-period of time. Tax revenues increase with raise in exemption age in 2015, but result is boosted by a concomitant increase in the tax rate.

The case of MT does not produce interpretable results within a difference-in-differences framework. Prior to policy change, the state does not present parallel trends with its neighboring-comparison group, thus an assumption of parallel trends for the period after treatment is implausible.

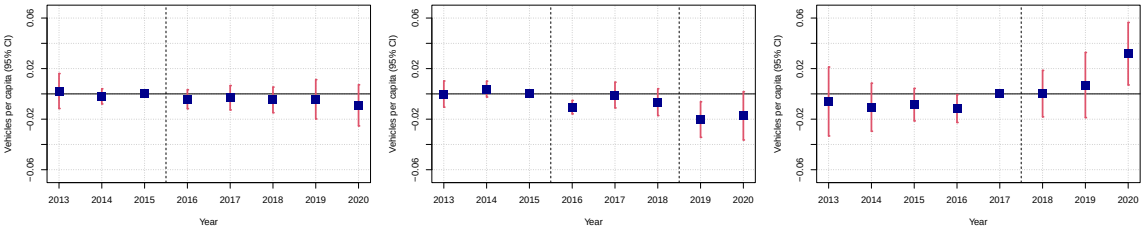
Figure F.4: Event-Study: Vehicles Characteristics and Taxation Revenue

(a) Panel A: Average Vehicle Age



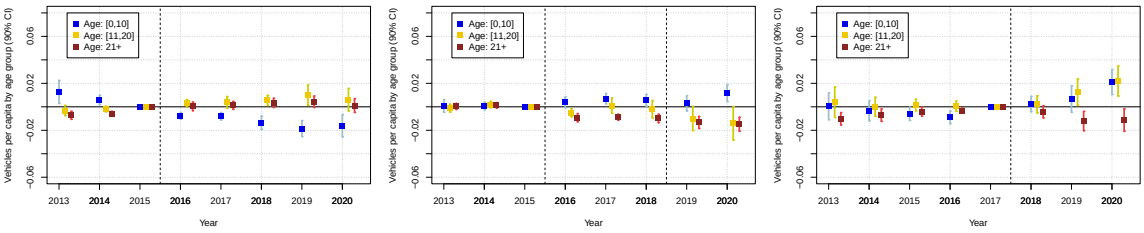
MS: 15 → 20, TO: 15 → ∞ GO: 10 → 15 → 10 MT: ∞ → 18

(b) Panel B: Vehicles per capita



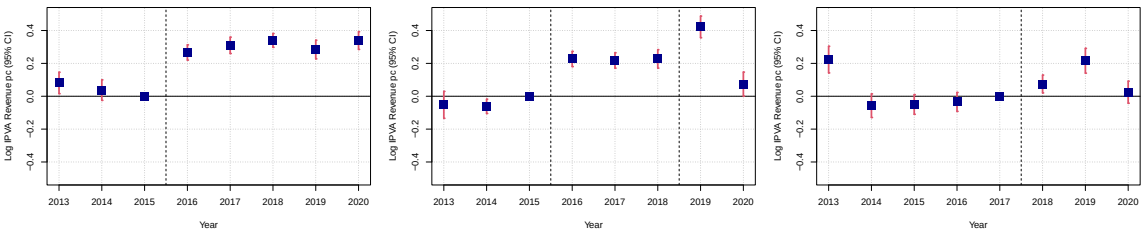
MS: 15 → 20, TO: 15 → ∞ GO: 10 → 15 → 10 MT: ∞ → 18

(c) Panel C: Vehicles per capita by age group



MS: 15 → 20, TO: 15 → ∞ GO: 10 → 15 → 10 MT: ∞ → 18

(d) Panel D: Log Municipality IPVA Revenue per capita



MS: 15 → 20, TO: 15 → ∞ GO: 10 → 15 → 10 MT: ∞ → 18

Notes: MS and TO raise exemption threshold in 2015 from 15 years to 20 and "No exemption". In 2015, GO raised the threshold from 10 to 15, but lowered cutoff in 2018. MT had no exemption age policy, and in 2017 introduced an exemption for vehicles 18 years or older. Policy changes take effect in the following year. 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 and controls described in the methodology subsection.

G Political Economy Implications Appendix

G.1 Background

Between the election cycles of 2014 and 2018, four states introduced changes to *IPVA*'s exemption age threshold. From these we are able to analyze the political impacts of three cases: i) Mato Grosso do Sul (MS) raises age cutoff from 15 to 20 years in 2015; ii) Goiás (GO) increases the exemption age from 10 to 15 years in 2015 but reverts it back to 10 years in 2018; iii) Mato Grosso (MT) institutes an 18 year threshold for exemption in 2017 and there were no previous age exemptions in the state. We cannot analyze the political impacts in a fourth case in the state of Tocantins (TO), which moved from a 15-year cutoff into "No Exemption", because the incumbent governor is removed from office mid-cycle due to campaign financing investigations, triggering a special election. We provide a timeline and more details of each case here.

Mato Grosso do Sul (MS): Reinaldo Azambuja (party: PSDB) wins the 2014 gubernatorial elections against two main opponents: Nelson Trad Filho, member of then incumbent governor's party PMDB; and Delcidio Amaral, member of PT, the party then holding Brazil's presidency. Following Azambuja's governorship proposal, in September 2015, the state assembly approves the Law Project 214/2015 to take effect in 2016, raising vehicle exemption age threshold from 15 to 20 years.[7] In 2018, Azambuja runs again for governor, now as an incumbent, and wins the election against main opponent Odilon de Oliveira (PDT).

Goiás (GO): Marconi Perillo (party: PSDB), the incumbent state governor, wins the 2014 governor election against main rival Iris Rezende (PMDB). In September 2015, under a larger state tax reform backed by the state's executive branch, the state assembly approves raising the exemption age cutoff from 10 to 15 years.[8] A new law change was made in February 2018 to revert the threshold to 10 years with approval of both assembly and governor.[9] In April 2018, Perillo leaves the position of state governor to run for a senate seat in the same year, leaving the governor's position to then vice-governor Jose Eliton (PSDB), who proceeds to run for governor's office. Both lose the elections in October that year.

Mato Grosso (MT): Pedro Taques (party: PDT) wins the 2014 gubernatorial election against main opponent Ludio Cabral (PT), who had the then-incumbent governor's party (PMDB) within his coalition. In 2015, while sitting governor, Taques switches parties to

[7] 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.

[8] News of law approval: https://www.auditece.org.br/noticia/goias-governador-sanciona-lei-que-aumenta-impostos.

[9] News of law sanctioning: https://folhaz.com.br/noticias/ipva-para-carros-com-mais-de-10-anos/.

PSDB, which was part of his governing coalition. In 2017, the state assembly, without the support of the executive branch, proposes a new law project that exempts from *IPVA* vehicles with more than 18 years. The governor vetoes the exemption arguing financial losses to the state, but the veto is overruled by the assembly and takes effect starting the following year. [10] The governor attempts reelection in 2018 but is defeated in October.

Tocantins (TO): Marcelo de Carvalho Miranda (party: PMDB) wins the 2014 gubernatorial election against main adversary Sandoval Cardoso (SD), who had become acting governor that same year after the resignation of the state's governor and vice-governor. In the context of a major state tax reform, in 2015, state assembly and governor approve the removal of age exemptions to the *IPVA*.[11] In early 2018, governor Miranda is removed from office by the Electoral Supreme Court amid an investigation of past campaign financing irregularities. This event triggered a special election won by Mauro Carlesse (PHS), then president of the state assembly, and who also won the regular election later in the same year.

G.2 Back-of-the-Envelope Calculation of Votes per Vehicles

Our regression estimates present the effect of a 1p.p. change in the share of vehicles impacted by policy on the incumbent's party vote share in governor's election, measured in percentage points.

$$\gamma = \frac{\partial PctVote}{\partial PctVeh}$$

We want to calculate the implied effect of 1 additional vehicle impacted by the policy on the votes to the incumbent party.

$$\tilde{\gamma} = \frac{\partial Vote}{\partial Veh}$$

Using the mechanical relations between number of votes and vehicles and percentage shares, we can use the chain rule to obtain the implied $\tilde{\gamma}$ from our estimated γ's.

$$\tilde{\gamma} = \frac{\partial Vote}{\partial PctVote} \times \gamma \times \frac{\partial PctVeh}{\partial Veh}$$

We can use the following mechanical relations:

$$\frac{\partial Vote}{\partial PctVote} = \frac{N_{ValidVotes}}{100}$$

[10] News of the exemption enactment: https://g1.globo.com/mato-grosso/noticia/2017/03/almt-aprova-lei-que-isenta-do-ipva-veiculos-com-mais-de-18-anos.html.

[11] Note from the state government: https://www.to.gov.br/noticias/veiculos-com-15-ou-mais-anos-de-fabricacao-devem-pagar-ipva/4nxs0xaqkgo8.

$$\frac{\partial PctVeh}{\partial Veh} = \frac{100}{N_{Veh}}$$

Such that:

$$\tilde{\gamma} = \gamma \times \frac{N_{ValidVotes}}{N_{Veh}}.$$

Using the statistics from our treated sample in the periods post policy change, we can calculate back-of-the-envelope estimates of the implied votes lost/gained per vehicle that lost/gained exemption status.

G.2.1 Sample Statistics

Table G.1: Voting-Power-Weighted Municipality Averages in Election Years

	2014 Election		2018 Election	
	Control	Treated	Control	Treated
Panel A: Governor Race – MS+GO v Neighbors				
Vote Share(%)	23.31	32.02	14.67	35.49
Votes on Party	271,956.07	42,694.01	193,588.49	80789.37
Valid Votes	1,346,435.28	181,694.03	1,387,052.60	190,111.91
Vehicles Under Old Exemption (%)	79.88	66.35	76.61	60.77
Vehicles Lost Exemption (%)	-	-	-	12.31
Vehicles Under Old Exemption	1,084,554.64	151,152.90	1,235,306.74	169,099.31
Vehicles Lost Exemption	-	-	-	26,356.52
Vehicles	1,380,332.15	205,444.23	1,651,940.34	246,527.16
Valid Votes / Vehicles	0.98	0.88	0.84	0.77
Panel B: Governor Race – MT v Neighbors				
Vote Share (%)	34.77	55.70	21.82	15.10
Votes on Party	10,809.66	11,093.94	5,130.10	2,983.82
Valid Votes	26,658.48	18,373.59	27,815.24	18,792.25
Vehicles Above Exemption (%)	17.57	-	25.58	18.43
Vehicles Gained Exemption (%)	-	-	-	18.43
Vehicles Above Exemption	5,808.22	-	10,490.38	5,933.04
Vehicles Gained Exemption	-	-	-	5,933.04
Vehicles	32,505.10	26,494.11	41,435.65	34,399.44
Valid Votes / Vehicles	0.82	0.69	0.67	0.55

Notes: Values are weighted averages based on the municipality's share of total votes in state at each governor election.

G.2.2 Votes per Vehicle

Table G.2: Back-of-the-Envelope: Impacts of Policy Change on Votes Changed per Vehicle

	$\hat{\gamma}$ (1)	Votes per Vehicle (2)
Panel A: GO+MS v. Neighbors – Lost Exemption		
Governor	-2.30^{*}	-1.77^{*}
	(1.20)	(0.93)
State Assembly	-0.15^{*}	-0.12^{*}
	(0.09)	(0.07)
Panel B: MT v. Neighbors – Gained Exemption		
Governor	0.27	0.15
	(0.54)	(0.30)
State Assembly	0.45^{**}	0.25^{**}
	(0.20)	(0.11)

Notes: In column (1), coefficients $\hat{\gamma}$ from Table 3 representing interaction between policy change and percentage of vehicles that lost/gained exemption status, and accompanying standard errors are reported in parentheses. Coefficients in column (2) are calculated using the formula $\hat{\gamma} \times (N_{ValidVotes}/N_{Veh})$ based on the statics from Appendix Table G.1. Standard Errors in column (2) are computed via Delta Method and reported in parentheses. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

H Marginal Value of Public Funds Appendix

Building on our analysis of the political and fiscal implications of policy changes, we leverage the cases of Goiás (GO) and Mato Grosso do Sul (MS) to calculate a marginal value of public funds (MVPF) object of a "more generous" (lower age) exemption threshold.

We reintroduce the general formula for the MVPF, from Equation 1:

$$MVPF(\bar{a}) = \frac{\tau V(\bar{a}) f(\bar{a};\bar{a})}{dR(\bar{a})/d\bar{a}} - \kappa \frac{dH(\bar{a})/d\bar{a}}{dR(\bar{a})/d\bar{a}}.$$

We can recover all relevant terms using the data from GO and MS. The change in revenue induced by policy change ($dR(\bar{a})/d\bar{a}$) is estimated in Table 4. The population's willingness to pay for the policy's health externalities is approximated with changes in public healthcare expenditures estimated in Table 4. Information on tax rate (τ) for different types of vehicles for each state are available; however, due to lack of information on fleet composition by type and age, a fleet-average tax rate cannot be calculated directly, instead we utilize the gasoline passenger vehicle tax rate. Next, we detail how we estimate the terms $V(\bar{a})$ and $f(\bar{a};\bar{a})$.

H.1 Counterfactual Fleet Age Distribution

We employ a simple Difference-in-Differences design to obtain the realized and counterfactual fleet age composition in the states of Goiás (GO) and Mato Grosso do Sul (MS). Using fleet shares by age bins as outcome variables, we estimate the following Equation:

$$y_{m,t} = \alpha + \eta Treat_m + \delta Post_t + \varphi Treat_m \times Post_t + \nu_{m,t}. \tag{H.1}$$

The sum of parameters $\alpha + \eta + \delta$ captures the counterfactual fleet share in a given age bin had the treated states (GO and MS) kept their "more generous" exemption policy under a parallel trends assumption. The sum $\alpha + \eta + \delta + \varphi$, in turn, represents the realized shares in the treat states after the policy change.

The pre-treatment, counterfactual, and realized fleet shares by age group in the treated states are presented in Table H.1. The age bins $[11, 15]$ and $[16, 20]$ represent the share of marginally-exempted groups, $f(\bar{a};\bar{a})$, in GO and MS, respectively. We utilize the counterfactual marginally-exempted shares for each state when calculating the MVPF of an increase in exemption "generosity".

Table H.1: Fleet Age Distribution in GO and MS: Counterfactual and Realized Shares

Dependent Variables:	Share of Vehicles Aged :				
	$[0,5]$	$[6,10]$	$[11,15]$	$[16,20]$	$[21,\infty)$
Pre-Treatment Average $(\hat{\alpha}+\hat{\eta})$	0.349	0.212	0.134	0.107	0.198
Counterfactual Average $(\hat{\alpha}+\hat{\eta}+\hat{\delta})$	0.262	0.248	0.157	0.101	0.231
Realized Average $(\hat{\alpha}+\hat{\eta}+\hat{\delta}+\hat{\varphi})$	0.250	0.264	0.149	0.109	0.228

Notes: This table presents the estimated fleet shares $\left(\widehat{f(a;\bar{a})}\right)$ in each age bin in the states of GO and MS in three scenarios: i) average shares before treatment (Pre-Treatment), ii) post-treatment if it had not been enacted (Counterfactual), and iii) actual post-treatment result (Realized). Estimates are obtained using a simple DiD design during the 2013-2018 time-frame following Equation H.1. Observations are at the municipality-year level and weighted by the 2010 population.

H.2 Average Vehicle Value by Age Group

To obtain a measure of average vehicle value per age group $V(a)$, we make use of the IPVA tax-revenue identity:

$$R(\bar{a}) = \sum_{a \leq \bar{a}} \tau V(a) f(a;\bar{a}).$$

Employing the gasoline passenger vehicle tax rate for each state as our measure for τ_s, we construct a tax-adjusted measure of revenue per vehicle:

$$\tilde{r}_{m,t} = \frac{R_{m,t}}{N_{m,t}} \frac{1}{\tau_s}.$$

In this exercise, we use the consolidated IPVA revenue, accounting both the half that stays with the municipal government and the half that goes to the state government.

Given the constructed $\tilde{r}_{m,t}$, the exemption thresholds in each state $\bar{a}_s$, and the local shares of vehicles by age group $(f(a)_{m,t})$, we can estimate the average vehicle value by age group $\widehat{V(a)}$. Empirically, we implement this by estimating the following Equation:

$$\tilde{r}_{m,t} = \left(\sum_{a} \vartheta_a \mathbf{1}(\bar{a} \geq a) f(a)_{m,t} \right) + \eta_s + \varepsilon_{m,t}.$$

The parameter $\hat{\vartheta}_a = \widehat{V(a)}$ captures the average vehicle value for the age group a. The state fixed effect η_s controls for state-specific time-invariant heterogeneities, such as potential different levels of tax non-compliance or divergences between the average-fleet and the gasoline

passenger vehicle tax rates.

Table H.2: Estimating Average Vehicle Value in Age Group

Dependent Variable:	Tax-Rate-Adjusted IPVA Revenue $\tilde{r}_{m,t}$ (1)
$\mathbf{1}(\bar{a}_s \geq 5) \times$ Share Vehicles Aged [0,5] ($\hat{\vartheta}_{[0,5]}$)	23,105.2***
	(2,648.4)
$\mathbf{1}(\bar{a}_s \geq 10) \times$ Share Vehicles Aged [6,10] ($\hat{\vartheta}_{[6,10]}$)	18,992.8***
	(3,712.4)
$\mathbf{1}(\bar{a}_s \geq 15) \times$ Share Vehicles Aged [11,15] ($\hat{\vartheta}_{[11,15]}$)	10,208.9
	(7,293.9)
$\mathbf{1}(\bar{a}_s \geq 20) \times$ Share Vehicles Aged [16,20] ($\hat{\vartheta}_{[16,20]}$)	11,818.0
	(7,950.0)
Regression statistics	
Observations	1,234
R^2	0.681

Notes: This table presents our estimates for average vehicle value at each age group ($\hat{\vartheta}_a = \widehat{V(a)}$). Observations are at the municipality-year level and weighted according to the 2010 population. Errors are clustered at the municipality level. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Our estimates for average vehicle value by age group are presented in Appendix Table H.2. We observe a downward trend in vehicle value with respect to age, in accordance with vehicle depreciation. However, average values also respond to the change in fleet composition; thus, the typical earlier retirement of motorcycles or other cheaper vehicles lessens this downward trend.

H.3 Relevant Statistics

To calculate the MVPF we need in place a few statistics of the treated states. We compute the vehicle per capita ratio for each state, and report the gasoline passenger vehicle tax rate. Results are displayed in Appendix Table H.3.

Table H.3: Relevant Treated States Statistics in Pre-Treatment Period, 2013-2015

States:	GO	MS	GO+MS
Vehicles per capita	0.47	0.55	0.50
IPVA Tax Rate	0.025	0.05	0.036

Notes: Reported IPVA tax rate is the gasoline passenger vehicle tax rate. Statistics were computed via OLS, with observations at the municipality-year level and weighted according to 2010 population. Implied state weights from regression were 0.57 for Goiás (GO) and 0.43 for Mato Grosso do Sul (MS).

H.4 Calculating the MVPF

Based on the statistics computed, we can calculate the MVPF of an increase in "generosity" in exemption for the treated states.

First, pooling the treated states of Goiás (GO) and Mato Grosso do Sul (MS), we compute the willingness to pay for the private benefit:

$$\begin{aligned}\tau V(\bar{a}) f(\bar{a};\bar{a}) &\approx 0.57 \times (0.025 \times 10,208.9 \times 0.157) + 0.43 \times (0.05 \times 11,818.0 \times 0.101) \\ &\approx \$48.50 \text{ BRL per vehicle.}\end{aligned}$$

The value is calculated based on each states' population weights and tax rate is gasoline passenger vehicle tax rate from pre-treatment period from Appendix Table H.3. Average vehicle value for each state's marginally exempted age group is retrieved from Appendix Table H.2. Shares of fleet from each relevant age group are the counterfactual shares in absence of policy change from Appendix Table H.1. Calculation implies a WTP for the private benefit of the policy of 48.50 BRL per vehicle annually. Based on the motorization statistics in treated states, this implies a WTP of 24.25 BRL per capita.

Based on the consolidated IPVA revenue effect of raising the exemption threshold in MS and GO, estimated in Table 4, we compute the fiscal effect of increasing "generosity":

$$\frac{dR(\bar{a})}{d\bar{a}} = \$35.8 \text{ BRL per vehicle.}$$

Based on the motorization statistics in treated states, this implies a fiscal effect of 17.9 BRL

per capita annually.

Using the effect of the policy change on public healthcare expenditures from Table 4 as a measure of the population's willingness to pay for health-related externality costs of the exemption policy, we compute:

$$-\kappa \frac{dH(\bar{a})}{d\bar{a}} = -\$38.2 \text{ BRL per capita.}$$

With all elements at hand, we calculate the MVPF of a 5-year decrease in the exemption age threshold among the treated states as:

$$MVPF = \frac{\tau V(\bar{a}) f(\bar{a}; \bar{a})}{dR(\bar{a})/d\bar{a}} - \kappa \frac{dH(\bar{a})/d\bar{a}}{dR(\bar{a})/d\bar{a}} \approx 1.35 - 2.13 = -0.78$$

This statistic implies that for each \$1 BRL in revenue foregone by the state and local governments, the public incurs an additional welfare loss of \$0.78 BRL. Although the private benefits of the policy average to about \$1.35 BRL per \$1 BRL of revenue foregone, these are overshadowed by the negative health externalities imposed on the whole population.