Trade Liberalization and Mortality Rates: Evidence of Pro-Cyclical Mortality from Brazil *

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Abstract

We trace the evolution of all-cause mortality rates in Brazilian regions with varying exposure to trade-induced economic shocks before, during, and after liberalization reforms in the 1990s. We find consistent evidence of pro-cyclical mortality, with areas more exposed to tariff reductions experiencing larger declines in mortality across varying time horizons. The observed decline in mortality rates is evident across sex, age groups, and for both internal and external causes of mortality. We falsify the observed relationship between mortality and tariff reductions with analyses of causes of death that are plausibly unrelated to economic activity. Concerning proximate mechanisms involved in our finding of pro-cyclical mortality, we show that healthcare infrastructure expanded in local economies more affected by the trade-induced economic shock. This expansion was characterized by the increased capital-intensity of care, facilitated by the import of diagnostic technologies that reduce mortality from internal causes. We also find supporting evidence for the idea that pro-cyclical mortality is partially caused by a decrease in transport and non-transport-related accidents. Overall, our findings highlight an underappreciated dimension of trade policy effects, namely public health.

Keywords: Health outcomes; Trade Liberalization; Local economic shocks; Pro-cyclical mortality; Healthcare infrastructure; Capital-intensity of care.

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1 Introduction and Motivation

In the late 1980s, the Brazilian economy was protected against external competition by a complex system of trade barriers (Kovak, 2013; Kume et al., 2003). With the election of Fernando Collor de Mello, the new Brazilian administration launched a series of trade liberalization reforms involving the harmonization of tariff levels across all industries of the economy. From 1990 to 1995, the average tariff decreased from 30.5 percent to 12.8 percent but varied considerably across industries. Sectors like agriculture and mining experienced negligible changes in tariffs, while others, such as apparel and rubber underwent declines of roughly 30 percentage points (Dix-Carneiro & Kovak, 2015). Given preexisting regional differences in industry mix, these trade reforms produced strikingly different regional economic impacts.

Differential exposure to trade reforms by region produced variation in labor demand shocks, that in turn caused measurable changes in labor markets and firm survival across Brazilian regions. Dix-Carneiro and Kovak (2015) note that "regions that initially specialized in industries facing larger tariff cuts experienced prolonged declines in formal sector employment and earnings relative to other regions" with these labor market effects operating across workers of varying levels of education, age, sex, and employment tenure. These trade-induced economic shocks to local labor markets also caused changes in criminogenic conditions that led to measurable increases in homicide mortality across affected regions in Brazil (Dix-Carneiro et al., 2018).

Taking inspiration from Dix-Carneiro et al. (2018), we widened the scope of the mortality analysis by tracing the evolution of all-cause and cause-specific mortality rates in Brazilian regions before, during, and after liberalization reforms.[1] Brazil's trade reform in the 1990s provides an excellent analytical setting in which to study the causal relationship between mortality and economic dynamics. As with previous research (Ruhm, 2000, 2015), we find consistent evidence of pro-cyclical mortality in Brazil, with the local economies most affected by trade-induced shocks witnessing substantial declines in all-cause mortality rates. Charris et al. (2023) find a similar result of relative decline in infant mortality in locations facing larger tariff reductions in Brazil. Our results indicate that the mortality effect is consistently observed for all subgroups by age and sex and across cause-specific sources of mortality. Our placebo exercises confirm that pre-reform mortality trends in each region bore no correlation to the subsequent trade-induced shocks. Moreover, the relationship between mortality and trade-induced economic shock is falsified with analyses of causes of mortality unrelated to economic activity like exposure to forces of nature and poisonous animals and plants.

These observations affirm that our findings capture the causal impact of trade-induced shocks on mortality. Our baseline specification indicates that a region facing a tariff reduction of 0.1 log points - reflecting a shift from the ninetieth percentile to the tenth percentile of regional tariff changes - exhibited a corresponding reduction of about 0.1 log points in

[1]For contextualization, homicide-related fatalities constituted a minor fraction accounting for less than 4% of the total deaths within the country on average between 1985 and 2010.

mortality rates. This translates to a 10 percent decrease in the all-cause mortality rate, five years subsequent to the completion of liberalization reforms, and about 0.2 log points (or 18 percent), fifteen years after the reform.

Our investigation into the mechanisms underlying pro-cyclical mortality reveals important insights, adding to the existing body of literature in health economics. First, we corroborate previous work (Ruhm, 2000, 2015), finding that the decline in mortality from external causes is attributable to a reduction in transport and non-transport-related accidents. Second, and unique to the Brazilian case, we find that the observed decrease in mortality rates from internal causes in regions more exposed to tariff cuts can be attributed to the relative increase in government spending on health.

Following the enactment of Brazil's federal Constitution and the establishment of the *Sistema Único de Saúde* (Unified Health System - SUS) in the late 1980s, we find evidence of increased spending per hospitalization and hospital procedures, as well as a notable increase in non-basic procedures compared to basic ones (i.e., more capital-intensive procedures) within the outpatient system of SUS in the local economies more impacted by the trade-induced economic shock. Specifically, we document a substantial increase in procedures aimed at detecting malignant tumors in these regions. These findings provide empirical support for the hypothesis that the reduction in deaths from internal causes, particularly from cardiovascular diseases and neoplasms in the harder-hit local economies was due mainly to a pronounced expansion of healthcare infrastructure toward prevention and diagnostic services, surpassing the growth observed in areas with lower exposure to tariff reductions. Of pivotal importance, our study uncovers a distinctive facet of the trade liberalization episode. We provide evidence that the trade-induced economic shock impacted the accessibility and affordability of imports which, in turn, directly facilitated the expansion of capital-intensive healthcare infrastructure and "life-saving" technologies, particularly within regions bruised by tariff adjustments.

The present study contributes to the extensive literature on the relationship between economic shocks and health outcomes (see Ruhm (2012) for a comprehensive review). Existing research consistently demonstrates that death rates, particularly at regional levels (Lindo, 2015), tend to decline during economic recessions and rise during economic upturns in developed countries.[2] However, evidence concerning developing countries is limited and less conclusive compared to the observed patterns in high-income nations.[3] We extend the literature by examining the long-term dynamics of mortality associated with a lasting shock that predominantly impacted urban regional markets within a developing economy. Particularly, our analysis capitalizes on a distinctive episode of trade liberalization, which closely resembles

[2] Various studies conducted for the United States (Miller et al., 2009; Ruhm, 2000, 2003, 2005, 2015; Stevens et al., 2015) and other developed nations (Ballester et al., 2019; Haaland & Telle, 2015; van den Berg et al., 2017) have observed this pro-cyclical pattern.

[3] For example, Gonzalez and Quast (2010) and Arroyave et al. (2015) document counter-cyclical mortality patterns in poorer areas of Mexico and among working-age men in Colombia, respectively. Hone et al. (2019) demonstrate that the recent Brazilian recession (2014-2016) led to increased mortality at the municipal level, although health and social protection expenditures appeared to mitigate adverse health effects.

a once-and-for-all event, providing us with a valuable opportunity to address identification challenges commonly encountered in country-level studies, establishing a causal relationship between local economic shocks and mortality rates. Lastly, this paper also contributes to a recent body of work that examines the implications of economic shocks resulting from trade policy changes on adult health outcomes (Autor et al., 2019; Lang et al., 2019; McManus & Schaur, 2016; Pierce & Schott, 2020).

In the next section, we describe data sources and our empirical strategy in pursuit of the causal relationship between mortality and trade-induced economic shocks. In Section 3, we report results on all-cause mortality and then results on age-specific mortality rates and cause-specific sources of death. Section 4 presents a robustness check on our identification strategy. In Section 5 we examine potential mechanisms underlying the effect of the trade-induced shock on internal causes of mortality, focusing on cardiovascular diseases and neoplasms, and, lastly, Section 6 concludes this paper with a recapitulation of the results and a discussion of implications.

2 Data Description and Empirical Strategy

2.1 Trade Liberalization and Local Economic Shocks

In the era prior to liberalization, the Brazilian economy was regulated by a wide array of protective measures aimed at limiting competition from abroad. These measures encompassed both non-tariff barriers and tariffs (Kume et al., 2003). Subsequent to trade liberalization initiatives launched by the newly elected government in March 1990, there was a notable decline in the average import tariffs across various industries. From 1990 to 1995 tariffs decreased by an average of approximately 17 percentage points. The standard deviation in nominal tariffs decreased from 14.9 percent to 7.4 percent in the same period (Dix-Carneiro, 2014), pushing the country toward greater harmonization of tariff levels across industries (Dix-Carneiro et al., 2018).[4] Figure 1 shows the percentage change in tariffs across main industries.

Because of preexisting regional variation in industry mix, these tariff reductions impacted the regions of Brazil heterogeneously. Following the literature on the regional labor market effects of foreign competition (Dix-Carneiro, 2014; Dix-Carneiro & Kovak, 2015; Hirata & Soares, 2020; Kovak, 2013; Ponczek & Ulyssea, 2022), our measurement of trade-induced shocks to local labor demand exploits the coincidence of sector-specific tariff change and the preexisting composition of employment across sectors at the regional level. The average tariff change faced by region r weighted by the importance of each sector in regional employment - our shift-share or "Bartik" instrument (Bartik, 1991; Borusyak et al., 2022) - is defined as

[4] The correlation coefficient between tariff cuts between 1990 and 1995 and the pre-liberalization tariff levels (in 1990) is near to -0.9, as sectors with initially higher tariffs experienced larger subsequent reductions. Figure A.1 presents a simple visualization of the relationship between tariff changes and pre-liberalization levels for each industry.

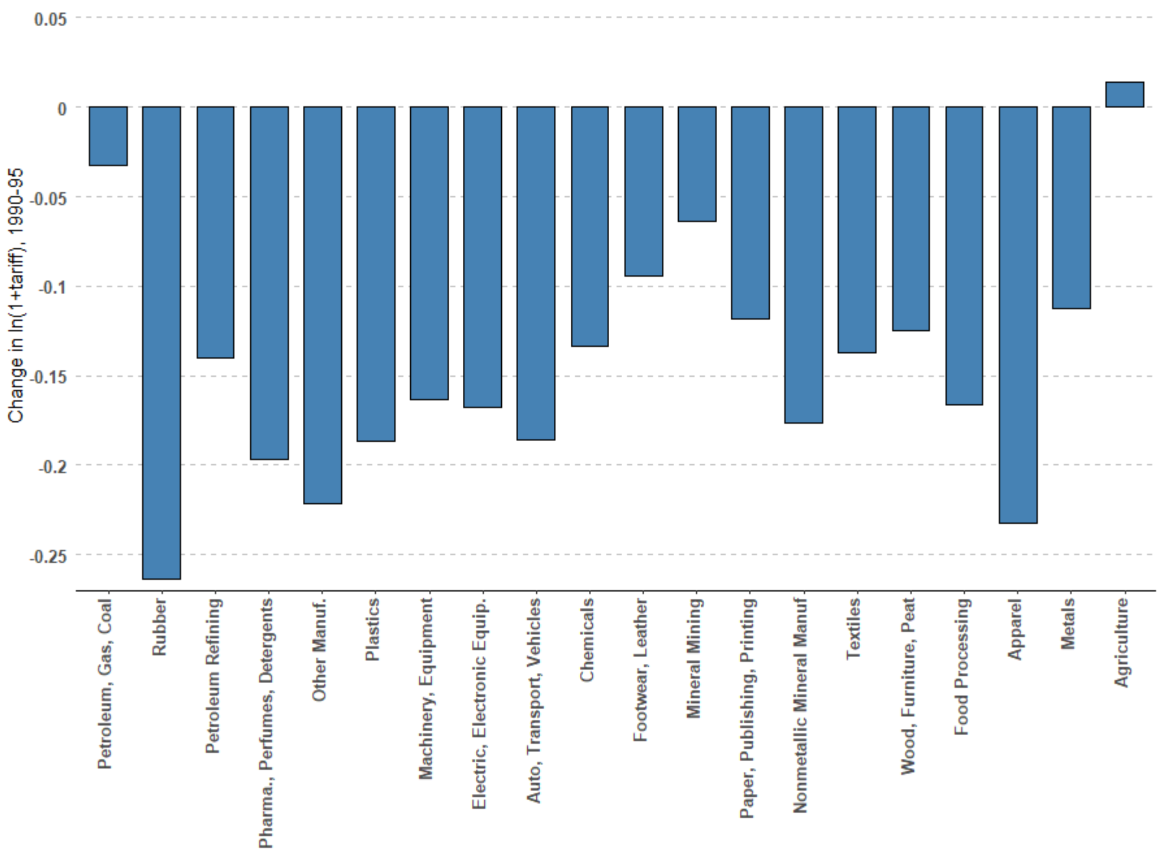


Figure 1: Nominal tariff changes, 1990-1995

Notes: Following Dix-Carneiro and Kovak (2017), we aggregate tariff data from Kume et al. (2003) to allow for a classification that is consistent with the Demographic Census data used to construct local tariff shock measures. Industries are sorted - from left to right - by increasing participation in terms of national employment in 1991.

follows:

$$RTC_r = \sum_{i \in T} \eta_{ri} \Delta log(1+\tau_i), \text{ with } \eta_{ri} = \frac{\frac{\lambda_{ri}}{\delta_i}}{\sum_{j \in T} \frac{\lambda_{rj}}{\delta_j}} \tag{1}$$

where τ_i is the tariff on industry i, λ_{ri} is the initial share of region r workers employed in industry i, δ_i equals one minus the wage bill share of industry i and T denote the set of all tradable industries. From Equation (1) it is evident that the magnitude of the trade-induced regional shock depends on how the local tradable sector is affected.[5]

[5]For a detailed discussion of how the non-tradable sector is incorporated in this measure, see Kovak (2013).

2.2 Data Description

Our analysis is conducted at the micro-region level, involving groupings of economically integrated municipalities with similar geographic and productive characteristics. Micro-regions are defined by the Brazilian Institute of Geography and Statistics (IBGE - *Instituto Brasileiro de Geografia e Estatística*) and are commonly used in economic literature to characterize local labor markets in Brazil (Dix-Carneiro & Kovak, 2017; Dix-Carneiro et al., 2018; Hirata & Soares, 2020; Ponczek & Ulyssea, 2022). Our analysis deploys a crosswalk between municipalities and micro-regions detailed in Dix-Carneiro and Kovak (2015), arriving at a set of 411 repeatedly observed local economies.[6] Table A.2, in the Appendix, provides descriptive statistics at the micro-region level for the main variables used in our empirical analysis.

2.2.1 Tariff Changes

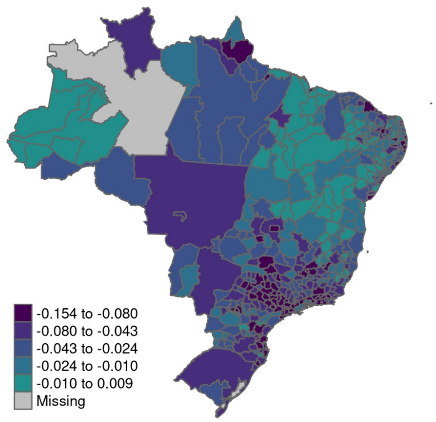
The tariff data used in this paper is provided by Kume et al. (2003), and is extensively used in the literature on trade and labor markets in Brazil (see, for instance, Kovak (2013), Dix-Carneiro and Kovak (2015, 2017)). We focus on changes in output tariffs to construct our measure of trade-induced local labor demand shocks (or regional tariff changes) described in Equation (1). Previous studies show that analyses using changes in effective rates of protection negligibly change results obtained using output tariff changes (Dix-Carneiro et al., 2018; Ponczek & Ulyssea, 2022).

2.2.2 Mortality Data

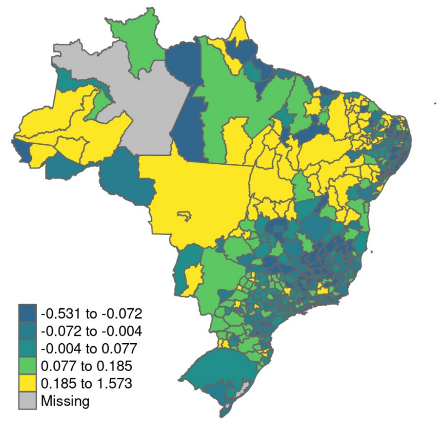
We use mortality records from DATASUS (administrative dataset from the Ministry of Health), available at the municipality level from 1979-1995 (ICD-9) and 1996-2020 (ICD-10). Although data are available since 1979, not all municipalities are observed until 1985 (Charris et al., 2023). Therefore, we exclude the 1979-1984 period from our analysis. For each specific cause of mortality, we compute the number of obits by municipality in each year and then aggregate to the micro-region level. Population data from four census waves (described in detail below), were used to calculate mortality rates per 100,000 inhabitants. Cause-specific sources of mortality examined in this paper are described in Table A.1.

Figure 2 visualizes the spatial coincidence between regional tariff shocks and mortality rates across micro-regions in Brazil. Panel (a) of Figure 2 presents the distribution of regional tariff changes. Panels (b) and (c) show, respectively, log changes in all-cause mortality rates across local economies for the medium-run (between 1991 and 2000) and long-run periods (between 1991 and 2010) after the trade-induced regional economic shocks. Suggestively, we find significant correlations between regional tariff changes and changes in local mortality rates, compatible with the pro-cyclical mortality literature.

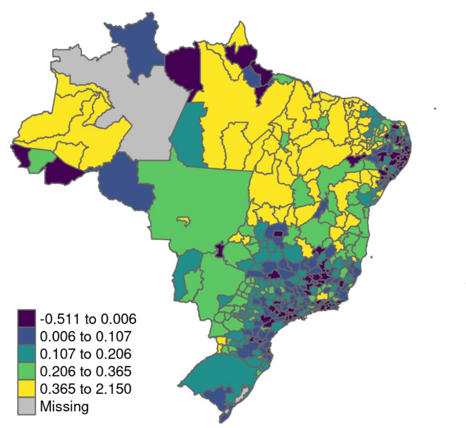
[6] Although we systemically observe 413 micro-regions, we exclude the regions of "Manaus" and "Fernando de Noronha" due to insensitivity to the trade liberalization reform.



(a) Distribution of regional tariff changes



(b) Distribution of log changes in local mortality rates: 2000–1991



(c) Distribution of log changes in local mortality rates: 2010–1991

Figure 2: Pre-trends, regional tariff changes, and post-liberalization log changes in mortality rates

Source: Mortality rates per 100,000 inhabitants computed from DATASUS. Regional tariff changes, RTC_r, are computed according to Equation (1).

2.2.3 Other Variables

We use four waves of the Brazilian Decennial Population Census, from IBGE, covering thirty years (from 1980-2010) to compute population sizes of micro-regions, as well as distributions by sex and age groups. Toward the investigation of mechanisms involved in pro-cyclical mortality, we computed annual government spending per category at the municipality level with data from the Ministry of Finance (*Ministério da Fazenda - Secretaria do Tesouro Nacional*), the number of health establishments from the *Pesquisa de Assistência Médico-Sanitária* (1992, 1999, 2002) and *Cadastro Nacional de Estabelecimentos de Saúde* (2005-2010), expenditures from the Brazilian Unified Health System (SUS - *Sistema Único de Saúde*) on outpatient care and procedures rates (per 100,000 inhabitants), hospital expenditures, hospitalization rates, and procedures of detection of malign tumors (measured in per 100,000 inhabitants).

2.3 Identification

Following Dix-Carneiro and Kovak (2015, 2017) and Dix-Carneiro et al. (2018) we assess the dynamic response of mortality rates to trade-induced regional economic shocks using the following specification:

$$\Delta_{91-t}log(kMR_r) = log(kMR_{r,t}) - log(kMR_{r,1991}) = \beta_t RTC_r + \alpha_{s,t} + \varepsilon_{r,t} \tag{2}$$

where $kMR_{r,t}$ is the k-specific mortality rate, described in Table A.1, in region r at time $t > 1991$ and $\alpha_{s,t}$ are state-time fixed effects.

Note that the difference-in-differences specification described in Equation (2) analyzes variation in RTC_r across micro-regions within states, providing transparent treatment-control comparisons (Dix-Carneiro et al., 2018). In all specifications, we cluster the standard errors at the meso-region (grouping of micro-regions also defined by IBGE) level to account for potential spatial correlation in outcomes.[7]

Recent research has provided a formal framework to establish the identifying assumptions for shift-share regression designs (Borusyak & Hull, 2023; Borusyak et al., 2022; Goldsmith-Pinkham et al., 2020). Building on the work of Goldsmith-Pinkham et al. (2020) and Borusyak et al. (2022), the identifying assumption in our specific context is that the trade-induced economic shock - RTC_r - is independent of local political and institutional dynamics across micro-regions.[8] This assumption is corroborated by the substantial correlation be-

[7]In the Online Appendix, we show the robustness of our results by using the inference procedures recommended by Borusyak et al. (2022) to address cross-region residual correlation in shift-share designs. While Adao et al. (2019) propose an alternative method for standard error estimation in such designs, it is important to note that Ferman (2022) has raised concerns about its suitability in settings like ours, with a relatively small number of industries where it may lead to excessive over-rejection (Alvarez et al., 2022; Ogeda et al., 2021).

[8]Given that we employ a linear shift-share design, where the exposure shares in all micro-regions sum up to one, the identification concerns raised by Borusyak and Hull (2023) do not apply to our specific research setting.

tween the tariff cuts and the pre-liberalization tariff levels, which, in turn, were determined by the level of protection established in previous decades. Consequently, concerns related to the political economy of the tariff reductions are alleviated, as sectoral and regional peculiarities appear to have minimal influence (Dix-Carneiro & Kovak, 2017; Dix-Carneiro et al., 2018; Goldberg & Pavcnik, 2007).

To ensure a causal interpretation of our estimates, a crucial assumption is that without the trade liberalization reform, local economies in Brazil would have experienced similar changes in mortality rates. We follow Dix-Carneiro and Kovak (2017) and incorporate pre-liberalization outcome trends in our analysis, which helps address potential confounding factors varying with trade-induced shock exposure. Unobservable shocks reflecting pre-existing long-run trajectories are accounted for by the pre-trend outcome control. To assess the validity of our research design, we provide a comprehensive set of estimates encompassing the periods prior to, during, and following the trade liberalization reform.

If our identifying assumption holds true, it is expected that areas with greater exposure to the reform and those with lower exposure would exhibit similar mortality trajectories before the reform, with divergence occurring only after its implementation. Our results broadly support this assumption. Furthermore, we conduct a falsification test to examine potential misleading correlations between declining mortality in local economies and the magnitude of tariff cuts. Our findings provide evidence that specific mortality rates, which are theoretically unrelated to economic conditions, remain unaffected by trade-induced regional economic shocks. Overall, the evidence underscores the unique nature of the Brazilian trade liberalization episode starting in the early 1990s, serving as a natural experiment facilitating the identification of the impacts of local economic shocks on mortality rates.

3 Results

3.1 Pro-cyclical Mortality

Table 1 presents estimates for Equation (2), describing effects for all individuals in the first row and then disaggregating for males and females separately. We start with a specification absent controls and weighting of observations. In column 1, our results indicate that there is a significant positive relationship between changes in mortality rates and regional tariff changes. The magnitude of the coefficient decreases marginally but remains statistically significant with the incremental saturation of the model, involving the weighting of the observations by the average population between 1991 and 2000 - for the medium-run - and, 1991 and 2010, for the long-run (column 2), the inclusion of state fixed effects (column 3) and a variable capturing the pre-period trend in mortality rates (columns 4 and 5).

Following Dix-Carneiro et al. (2018), we address concerns that preexisting trends in region-specific mortality rates could be correlated with (future) trade-induced local shocks. In column 4 we include this trend variable as an additional control and estimate the equation by ordinary least squares. A potential problem with this procedure is that the log of 1991 mortality rates appears on the right- and left-hand side of the estimating equation, potentially introducing a mechanical bias in the estimators (Dix-Carneiro et al., 2018). This problem is solved by using a ratio of the number of total obits in 1990 and 1985, $\left(\frac{TotalObits_{r,1990}}{TotalObits_{r,1985}}\right)$, as an instrument for the preexisting trends of mortality rates in a 2SLS estimation. In both cases there are modest changes in the coefficients of interest, suggesting that our estimated relationship between changes in mortality rates and regional economic shocks is not driven by preexisting trends. The coefficients associated with such pre-trends are not statistically significant (at the 5% significance level) in any of the specifications in Table 1. Going forward, and for ease of exposition, we only present the results of the specification of column 3, involving the weighting of observations by the population and state fixed effects.[9]

The medium-run results in Table 1 indicate that the effect of regional tariff changes on mortality rates is substantive: a change in RTC_r equivalent to -0.1 log points is accompanied by a decrease in all-cause mortality rates of at least 0.1 log points, or 10 percent. To provide context on the effect size, a micro-region at the mean of the 1991 mortality rate distribution with an average population size in 2000, would experience a decrease of approximately 400 deaths with a tariff shock of this size. Interestingly, the effects of the trade-induced regional economic shock on all-cause mortality rates appear stronger in the longer run, with a change in RTC_r equivalent to -0.1 log points being accompanied by a decrease in all-cause mortality rates of approximately 0.2 log points, or 18 percent. This pattern of steadily growing effects mirrors the longer-run dynamic of employment documented in Dix-Carneiro and Kovak (2017).

The consistency in the dynamic impacts of the trade reform on mortality and employment outcomes suggests that changes in local economic conditions – as highlighted by the pro-cyclical mortality literature – play a crucial role in explaining our findings. Utilizing similar back-of-the-envelope calculations, it can be inferred that a micro-region characterized by the average mortality rate from the 1991 distribution and possessing the average population in 2010 would witness a remarkable reduction of around 800 deaths in comparison to the observed average of 2700 deaths in the year 2010.

For perspective, the standard deviations of $\Delta_{91-00}log(MR_r)$ and $\Delta_{91-10}log(MR_r)$ across micro-regions are, respectively, 0.26 and 0.32 log points, so we document an increase of approximately 42% of a standard deviation in decadal changes in log mortality rates in the medium run and approximately 63% of a standard deviation in bi-decadal changes in log mortality rates in the long run caused by the trade-induced economic shock.[10] Overall, our results point to a strong positive relationship between the all-cause mortality rate and regional tariff changes.

A possible concern with the results above is that RTC_r may be correlated with pre-

[9] We show in detail the notable stability of the coefficients associated with the impact of the trade-induced shock on all-cause mortality rates for our preferred specification in the Online Appendix.

[10] In view of results presented by Dix-Carneiro et al. (2018), the intensification of pro-cyclical mortality conforms to the subsidence of the initial increase in the homicide rate, a component of all-cause mortality during the period analyzed in Brazil.

existing trends in the outcome of interest. Besides the inclusion of preexisting trend variables as additional controls, Column 6 of Table 1 presents evidence that regional tariff changes are uncorrelated with pre-trends by regressing pre-liberalization changes in mortality directly against (future) trade shocks (that is, using $\Delta_{85-91}log(MR_r)$ as the dependent variable). The non-significance of the coefficients in our placebo test corroborates the previous evidence obtained with the inclusion of trend variables in the estimations.

Table 1: Regional tariff changes and log changes in mortality rates

	OLS (1)		OLS (2)		OLS (3)		OLS (4)		2SLS (5)		Placebo (6)
Dep. var.: $\Delta log(MR_r)$	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1985-1991
All											
RTC_r	1.599***	3.162***	1.164***	2.496***	1.099***	1.957***	1.099***	1.958***	1.099***	1.958***	-0.00567
	(0.449)	(0.567)	(0.275)	(0.346)	(0.240)	(0.278)	(0.276)	(0.310)	(0.249)	(0.296)	(0.312)
$\Delta_{85-91}log(MR_r)$							-0.188	-0.256	-0.104	-0.239	
							(0.162)	(0.171)	(0.194)	(0.211)	
Male											
RTC_r	1.426***	3.368***	1.059***	2.857***	1.095***	2.103***	1.051***	2.051***	1.075***	2.062***	-0.229
	(0.472)	(0.549)	(0.298)	(0.327)	(0.246)	(0.245)	(0.292)	(0.287)	(0.259)	(0.20)	(0.321)
$\Delta_{85-91}log(MR_r)$							-0.199	-0.241	-0.0867	-0.189	
							(0.161)	(0.168)	(0.185)	(0.207)	
Female											
RTC_r	1.873***	2.876***	1.340***	2.053***	1.141***	1.788***	1.197***	1.874***	1.172***	1.868***	0.306
	(0.479)	(0.645)	(0.338)	(0.497)	(0.276)	(0.368)	(0.300)	(0.396)	(0.272)	(0.383)	(0.308)
$\Delta_{85-91}log(MR_r)$							-0.181	-0.270*	-0.0989	-0.250	
							(0.141)	(0.148)	(0.180)	(0.180)	

Notes: There are 411 micro-region observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. Unit of analysis r is a micro-region. In column 1, observations are not weighted; in column 2, observations are weighted by population;column 3 adds state fixed effects to column 2; column 4 adds pre-trends to column 3; column 5 shows two-stage least squares, with an instrument for $\Delta_{85-91}log(MR_r)$. Column 6 presents a placebo test, with observations weighted by population and considering state fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure 3 presents a graphical representation of the dynamic effects of tariff reductions on all-cause mortality rates. Importantly, the trade-induced shock starts to affect the mortality rate only after the end of the trade liberalization episode, with all-cause mortality increasingly reducing over time.

3.2 Age-Specific Effects

Because the risk of mortality increases with age, the declining trend in mortality might reflect changes in the age structure of micro-regions as opposed to shifting economic conditions. During our period of analysis, birth rates increased roughly three times faster than death rates, decreasing the average age of residents across micro-regions. To address this issue, we recapitulate our analysis for six different age groups. Table 2 presents the results from the estimation of the effect of local economic shocks on mortality rates for each age group. In the second column of Table 2, we include the share of deaths out of the total (average from 1985 - our initial data point - to 2010) for each group to help discern the economic relevance of estimated effects.

The results are quantitatively similar to those presented in column 3 of Table 1. The strongest impact of the local economic shock on mortality rates is observed in the first age group, from 0 to 14 years, in both the medium and long run. Infant mortality accounts for the

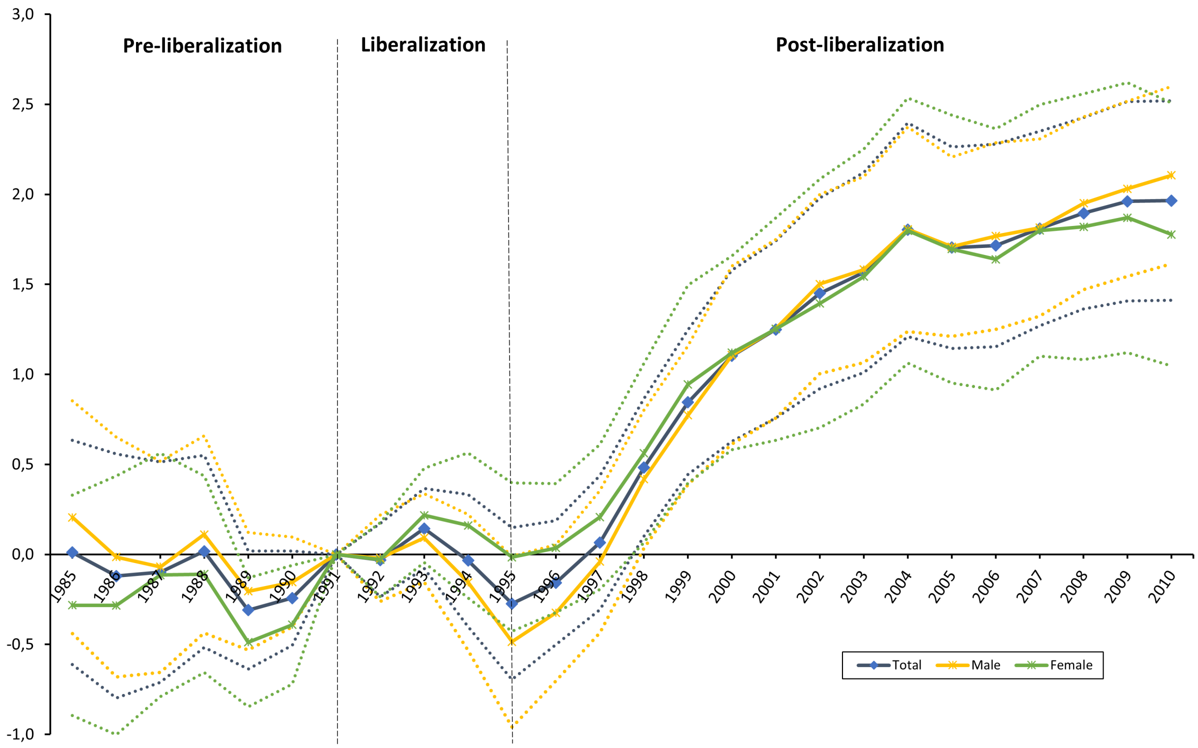


Figure 3: Dynamic effects of regional tariff changes on log changes in mortality rates

Notes: Each point reflects an individual regression coefficient $\hat{\beta}$ following Equation (2), where the dependent variable is the change in regional log all-cause mortality rates - total, male and female - and the independent variable is the RTC_r in $t = 1985, ..., 2010$. All regressions include state fixed effects. Dashed lines show 95 percent confidence intervals. Standard errors are adjusted for 91 meso-region clusters.

largest share of deaths in this age interval of 0 to 14. This result is compatible with Charris et al. (2023), showing a reduction in infant mortality at the municipality level in Brazil after the trade liberalization shock. The authors indicate that public policies pertaining to healthcare access focused on prenatal and newborn care had a significant impact on reducing infant mortality in the country, especially in the second half of the 2000s.

Concerning the medium run, the results for persons between 24 and 64 years of age are statistically significant and similar to the average effect of the trade-induced economic shock.[11] The result is less pronounced for elderly populations.[12] In the longer run, we observe

[11]The apparent reduction in the effect for persons 15-24 years of age in the medium run may be related to the increase in the homicide rate documented in Dix-Carneiro et al. (2018), which disproportionately affects this age group.

[12]The population over 75 years of age in Brazil was remarkably small in the early decades of our analysis. For example, according to census data, less than 2.5% of the country's total population in 2000 was over 75 years old.

Table 2: Regional tariff changes and log changes in group-specific mortality rates

Type of Mortality	Share of deaths	Estimated coefficients	
	Average 1985-2010	1991-2000	1991-2010
All deaths	1.000	1.099***	1.957***
		(0.240)	(0.278)
Sex-specific			
Males	0.579	1.095***	2.103***
		(0.246)	(0.245)
Females	0.421	1.141***	1.788***
		(0.276)	(0.368)
Age-specific			
0-14	0.131	2.859***	3.242***
		(0.657)	(0.907)
15-24	0.041	1.348	2.157***
		(0.884)	(0.727)
25-44	0.126	0.990***	2.653***
		(0.292)	(0.283)
45-64	0.238	1.452***	2.764***
		(0.227)	(0.335)
65-74	0.178	0.576***	1.749***
		(0.264)	(0.315)
75+	0.286	0.355	1.131***
		(0.270)	(0.296)

Notes: There are 411 micro-region observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. Unit of analysis r is a micro-region. In all regressions, observations are weighted and state fixed effects are added. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

an intensification of estimated effects for all age groups. In particular, the effect of tariff reductions amplifies for working-age populations, as expected from the direct relationship with the unemployment rate. Overall, the results in Table 2 suggest that the results reported in Table 1 are not driven by changes in age structure.

3.3 Cause-Specific Sources of Mortality

Next, we investigate the impacts of the traded-induced economic shocks on cause-specific sources of mortality. Following Ruhm (2015), we separately examine three diseases and four external causes of mortality. The three disease categories are: cardiovascular, cancer, and other diseases, accounting for 28%, 12%, and 49% of all deaths over the 1985–2010 period (average), respectively. The four external sources are: transport accidents, other (non-transport) accidents, homicides, and suicides. Those causes were responsible for 3.5%, 2.8%, 3.9%, and 0.7% of all deaths, respectively. Additionally, we decompose non-transport accidents into four specific types – falls, drowning/submersion, smoke/fires/flames, and poisoning/exposure to noxious substances. Table 3 presents the results for each source of death in both the medium and long run.

As shown in Table 3, the reduction in mortality from external causes is greater than that from diseases in regions most affected by the economic shock. In particular, deaths from transport accidents are most impacted by the tariff reduction - a change in RTC_r equivalent to -0.1 log points is accompanied by a large decrease in the transport accidents mortality rate of almost 0.6 log points (45 percent) in the medium run and of 0.8 log points (55 percent) after 20 years. This result is consistent with Ruhm (2000) and Miller et al. (2009) who argue that an increase in the unemployment rate reduces motor vehicle miles traveled and therefore number of fatal traffic accidents.[13] Results also indicate that the economic shock arising from trade liberalization efforts significantly reduced the mortality rate from non-transport accidents in Brazil. Intuitively, because of the observed increase in the unemployment rate, fatal non-transport accidents in work settings decreased.

Concerning deaths from disease, mortality rates from cardiovascular diseases and cancer are greatly reduced by trade-induced economic shocks in the medium run, and with the magnification of this effect in the long run - a change in RTC_r equivalent to -0.1 log points are accompanied by decreases in the mortality rates from cardiovascular disease and cancer of more than 0.26 log points (roughly 23 percent) in the medium run and of more than 0.6 log points, or 45 percent, after 20 years. By contrast, deaths from other diseases are less markedly reduced in the medium run, with the coefficient on the tariff change losing statistical significance in the long run. These results suggest that, although in the medium term the reduction in mortality from diseases may be explained by a common mechanism, in the long run it may be governed by other forces. We analyze in more detail the potential mechanisms behind the results for internal causes of mortality in Section 5.

4 Falsification

In the previous section, we presented extensive empirical evidence demonstrating that the Brazilian trade liberalization episode - which largely impacted the economic conditions of regional economies - led to notable decreases in mortality rates in the areas with greater exposure to the trade-induced economic shock. These findings support the notion that mortality rates are influenced by economic conditions and follow a pro-cyclical pattern during the analyzed period. Moreover, our investigation revealed a consistent downward trend in mortality across various age groups following the tariff reduction shock, attenuating doubt that our results merely reflect changes in the age distribution of the Brazilian population.

In addition to using instruments for pre-trends in the variables of interest and conducting

[13] Another contributing factor to this outcome could stem from trade liberalization's influence on import affordability. This, in turn, could have facilitated the revitalization of the country's automotive fleet, potentially reducing accidents. We show, in the Online Appendix, a notable surge in imports of automotive vehicles and parts in aggregate for Brazil, especially during the 2000s.

Table 3: Regional tariff changes and log changes in cause-specific mortality rates

Source of death	Share of deaths	Estimated coefficients	
	Average 1985-2010	1991-2000	1991-2010
Diseases	**0.891**	**0.935***** **(0.202)**	**1.703***** **(0.276)**
Cardiovascular disease	0.282	2.822*** (0.772)	6.226*** (0.968)
Cancer	0.120	2.695*** (0.676)	6.042*** (0.876)
Other diseases	0.489	0.607** (0.255)	0.107 (0.355)
External causes	**0.109**	**2.557**** **(0.985)**	**4.830***** **(0.678)**
Transport accidents	0.035	5.950*** (1.080)	8.093*** (1.671)
Other accidents	0.028	3.033*** (1.015)	4.705*** (1.123)
Suicides	0.007	1.560 (1.140)	2.177 (2.023)
Homicides	0.039	-3.855*** (1.445)	-1.311 (2.462)
Other accidents	**0.028**	**3.033***** **(1.015)**	**4.705***** **(1.123)**
Falls	0.006	2.620* (1.349)	2.398*** (0.694)
Drowning/submersion	0.007	5.209*** (0.725)	9.070*** (0.990)
Smoke/fire/flames	0.001	4.619*** (1.159)	3.982*** (0.949)
Poisoning/noxious	0.001	6.434** (3.108)	2.108 (1.803)

Notes: There are 411 micro-region observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. Unit of analysis r is a micro-region. In all regressions, observations are weighted and state fixed effects are added. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

placebo tests across our main specifications, we implement a falsification test to further assess the robustness of our findings. The logic is simple: if an omitted variable affects all mortality rates, then we would anticipate significant effects of regional tariff changes on causes of mortality unrelated to the economic conditions of local areas or economic cycles in general. For this falsification test, we examine mortality causes not linked to economic activity, specifically deaths due to natural forces or exposure to toxic animals and plants.

The results are summarized in Table 4. It is direct to note that, from the specifications in which we weight the observations by the population of each micro-region and consider state fixed effects (from column 2 to column 6), there is no statistical significance of the coefficients associated with the economic shock in the specific mortality rate in either time window.

Table 4: Regional tariff changes and log changes in "nature" mortality rates

	OLS (1)		OLS (2)		OLS (3)		OLS (4)		2SLS (5)		Placebo (6)
Dep. var.: $\Delta log(NMR_r)$	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1985-1991
RTC_r	2.389***	1.280	0.986	-7.350	1.780	-2.393	0.802	-2.836	1.698	-1.364	-1.513*
	(0.831)	(1.486)	(1.046)	(4.616)	(1.281)	(2.119)	(1.169)	(2.129)	(1.289)	(2.015)	(0.879)
$\Delta_{85-91} log(NMR_r)$							-0.626***	-0.275**	-0.0525	0.629	
							(0.103)	(0.134)	(0.162)	(0.369)	

Notes: There are 408 micro-region - the unit of analysis - observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. In column 1, observations are not weighted; in column 2, observations are weighted by population;column 3 adds state fixed effects to column 2; column 4 adds pre-trends to column 3; column 5 shows two-stage least squares, with an instrument for $\Delta_{85-91} log(NMR_r)$. Column 6 presents a placebo test, with observations weighted by population and considering state fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

These results indicate that there are likely no omitted factors or variables in our previous estimates that would have a universal impact on all mortality rates during the analyzed period. Our findings suggest that specific mortality rates, which are theoretically independent of economic conditions, remain unaffected by the trade-induced economic shock. This falsification test serves as a robustness check for our empirical approach and supports the credibility of our identification strategy.

5 Potential Mechanisms for Internal Causes

Next, we explore possible mechanisms underlying the effect of the trade-induced shock on internal causes of death.[14]

5.1 Healthcare Infrastructure

The enactment of Brazil's new federal Constitution in 1988, a few years before trade liberalization reforms, brought about a substantial increase in social spending aimed at fostering social development across the country. This constitutional reform had a profound impact on the country's institutional framework, particularly within the health sector. Brazil introduced the *Sistema Único de Saúde*, which now stands as the largest publicly-funded healthcare system globally. The legislative process leading to the creation of this health system ensured mandatory government spending on the health sector to guarantee universal access to healthcare as a right, resulting in the expansion of healthcare infrastructure

[14] It is worth noting that Dix-Carneiro and Kovak (2017) and Charris et al. (2023) find no evidence of shifts in migration patterns across local economies in response to the trade-induced economic shock. Consequently, the evidence suggests that selective migration is unlikely to be a key factor driving our results.

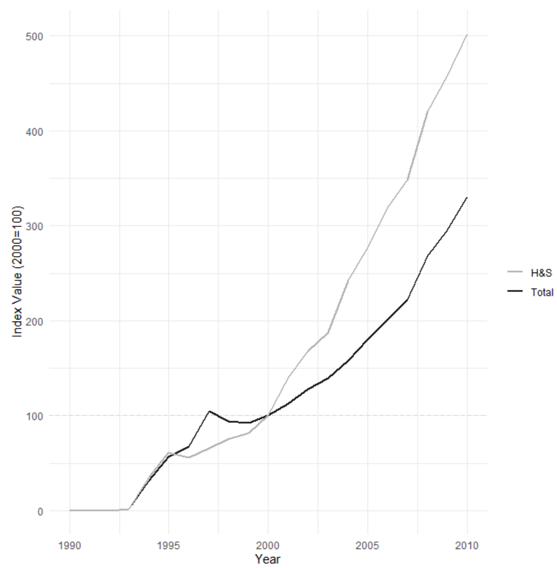
across different regions of the country. Moreover, health spending underwent decentralization from the 1990s onwards, aligning with a constitutional principle of decentralization in the administration of healthcare (Paim et al., 2011).[15]

Figure 4 depicts the evolution of public spending on "health and sanitation" (henceforth, H&S), as well as total expenditures by state and municipal governments in Brazil by year from 1990 to 2010. Panel (a) highlights the remarkable growth of H&S spending relative to total state expenditures, particularly from the late 1990s onwards. In 2010, Brazilian states collectively spent nearly five times more on H&S than they did in 2000. A similar trend is observed for municipal health expenditures, as shown in panel (b), with a four-fold increase between 2000 and 2010. To provide perspective, panel (c) presents the ratio of health and sanitation expenditures to total expenditures for both levels of government. The impact of decentralization in health management is evident, particularly for municipalities, with a sharp increase in health spending relative to total expenditures. As noted earlier, the most significant expansion in H&S spending occurred in the late 1990s or early 2000s, coinciding with the largest impacts of the trade-induced regional economic shock on internal causes of mortality.

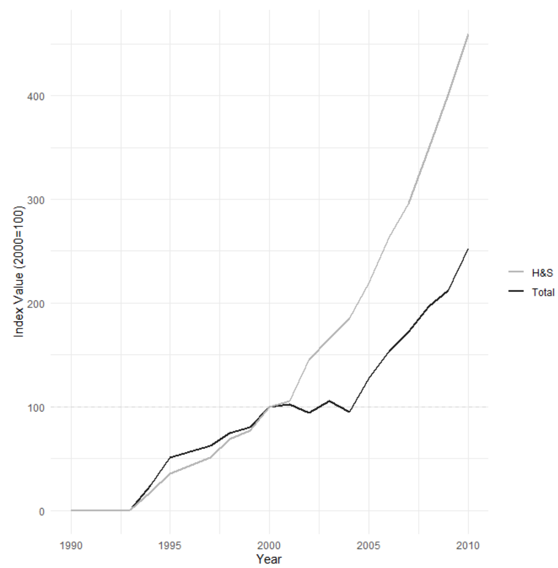
The precise reasons behind the uneven decline in mortality rates from cardiovascular disease and neoplasms in regions that experienced the greatest impact of the trade shock in the long run remain unclear. One plausible hypothesis suggests that the documented surge in healthcare expenditures has been allocated to the development of medium and high-complexity healthcare infrastructure, enhancing the accessibility and effectiveness of prevention, diagnosis, and treatment for these particular diseases. Notably, evidence of this phenomenon appears to have emerged in Brazil since the late 1990s.

Table 5 presents an overview of the supply and evolution of selected diagnostic imaging equipment - more directly related to these specific diseases - in Brazil from 1999 to 2005. In terms of the whole country, the number of units increased 20% compared to 1999, with the most significant change occurring from 2002 to 2005. Notably, magnetic resonance imaging (MRI), mammography, color Doppler ultrasound, and X-ray machines for hemodynamics experienced the most substantial changes during this period. The growth of other types of X-ray machines remained below the average, as did other ultrasound machines. This suggests that while simpler equipment, though more abundant in number, exhibited modest growth, the more advanced equipment demonstrated relatively greater expansion (IBGE, 2009).

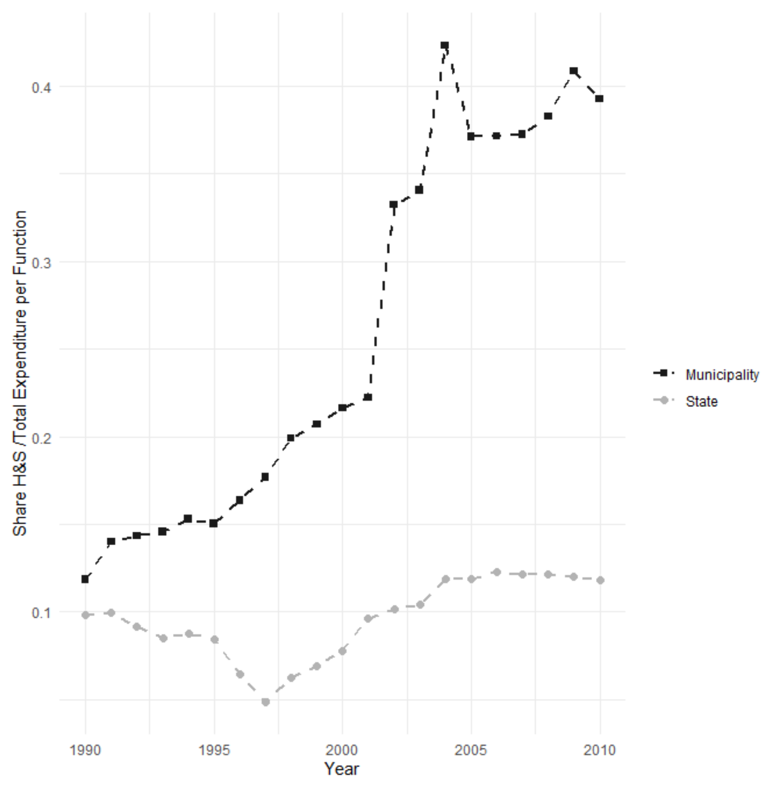
[15] Article 198 on the Brazilian Constitution indicates that, among other things, within a regionalized and hierarchical network, public health actions and services should function as a unified system, guided by the principle of decentralization. It also describes the allocation of obligatory resources for public health actions and services for all spheres of government.



(a) Expenditure per function: states



(b) Expenditure per function: municipalities



(c) Share of H&S in total expenditure

Figure 4: Trends in public expenditure for states and municipalities: 1990-2010

Source: Annual government spending per category both at the municipality and the state level is from the Ministry of Finance (STN - *Secretaria do Tesouro Nacional*).

Table 5: Diagnostic imaging equipment per selected type in Brazil: 1999-2005

Equipment	Total			Variation (%)	
	1999	2002	2005	Δ_{05-99}	Δ_{02-99}
Mammography	2065	2498	3245	57,1	21,0
X-Ray for Hemodynamics	355	451	537	51,3	27,0
Other X-Ray	17069	18538	18720	9,7	1,0
MRI	285	433	549	92,6	51,9
Tomography	1515	1617	1961	29,4	6,7
Ultrasound	11500	11849	14242	23,8	3,0
- *Doppler*	3921	4638	6185	57,7	18,3
- *Others*	7579	7211	8057	6,3	-4,9
Total	**32789**	**35386**	**39254**	**19,7**	**7,9**

Source: Data from IBGE (2009) and *Pesquisa de Assistência Médico-Sanitária*; 1999, 2002 and 2005.

Furthermore, the expansion of the supply of diagnostic equipment associated with the specific diseases that showed the largest reductions in mortality rates was even more pronounced when comparing 1999 to 2009. For instance, data from the 2009 Survey of Medical-Sanitary Assistance indicates that the number of MRI machines grew by 320% in a decade, while tomography equipment grew by nearly 100%. In terms of basic equipment for diagnosing cardiovascular diseases, the number of electrocardiographs increased by more than 60% over the same period.

According to IBGE (2009), the distribution of healthcare services in Brazil was characterized by significant inequality, a situation that was exacerbated when it came to the availability of selected diagnostic imaging equipment. Importantly, this unequal distribution pattern mirrors the regional distribution of the economic shocks resulting from trade liberalization. Regions such as the North and Northeast, which experienced relatively smaller changes in regional tariffs during the liberalization episode, faced significant delays in terms of the availability of advanced diagnostic imaging equipment compared to the national average. In contrast, the Southeast and South regions, which were more heavily impacted by tariff changes, witnessed a high concentration of such equipment throughout the 2000s. To provide context, the Southeast region alone accounted for approximately 58% of the CT scanners and over 61% of the MRI scanners in health establishments across the country, despite representing only 42% of the total population.

The available evidence thus far suggests some notable trends, particularly from the late 1990s onwards, which are of significant relevance to understanding the mechanisms underlying the impacts of the trade-induced economic shock on internal causes of mortality. First, there has been a substantial rise in health expenditures by municipal and state governments in Brazil, leading to the expansion of healthcare infrastructure throughout different regions of the country. Secondly, this expansion of healthcare infrastructure is closely linked to a marked increase in the availability of medium and high-complexity exams and procedures, at least concerning the necessary equipment associated with these procedures. Furthermore, it is worth noting that the increase in diagnostic and treatment equipment, particularly useful for cardiovascular diseases and neoplasms, appears to be concentrated in the more affluent regions of the country. Intriguingly, this expansion seems to coincide geographically with exposure to tariff reductions during the trade liberalization episode.

5.2 Impacts of Trade Liberalization

To examine the plausibility of this hypothesis, our investigation delves into evaluating the impacts of the trade-induced regional economic shock on various indicators related to healthcare infrastructure. These variables include government expenditure dedicated to healthcare, the proportion of total spending allocated to health, the production output of the Unified Health System (SUS), and the increase in advanced diagnostic services and procedures within the micro-regions of Brazil. Consistent with the empirical analyses previously presented in this study, we treat these variables as dependent variables and regress on our measure of the economic shock arising from the trade liberalization episode, RTC_r. The specification aligns with Equation (2). The outcomes of these analyses are summarized in Table 6.

In Panel A of Table 6, we describe the impact of the tariff cuts on government spending in the micro-regions (aggregating from municipality-level data). Looking at spending on H&S, it is notable that, while the coefficients are not statistically significant, there appears to be an increase in spending on health services in the regions more exposed to the tariff shock. Looking at the ratio of expenditures on H&S to total expenditures, we observe statistically significant increases both in the medium and in the long run.

Next, in Panel B, we examine the expenditures of both the hospital (SIH - *Sistema de Informações Hospitalares do SUS*) and outpatient (SIA - *Sistema de Informações Ambulatoriais do SUS*) systems of SUS. In the first column, note that expenditures on hospitalizations and hospital procedures increased significantly - economically and statistically - with the tariff shock in the medium and long run, with the latter effect being much larger. Similarly, per capita expenditure in the outpatient system increased both in the medium and long run after the trade liberalization episode. Moreover, we estimate the effect of the trade-induced economic shock on the number of health establishments to more directly assess the expansion of health infrastructure. In the medium run, the average number of establishments does not seem to change in the regions most affected by the tariff cuts. However, the total effect becomes statistically significant in the long run - that is, the local economies more exposed to the shock show a relative increase in the number of health establishments after almost two decades following liberalization.

These findings provide support for the hypothesis that regions most affected by the trade-induced economic shock experienced an expansion in their healthcare infrastructure. While Figure 4 demonstrates a substantial overall increase in health expenditure at the aggregate level for Brazilian municipalities, our analysis reveals that urban and industrial regional

Table 6: Potential mechanisms: regional tariff change and outcomes

Panel A. Local Government Spending	Expenditures per function		Expenditures H&S		Share H&S / Total	
	1995-2000	1995-2010	1995-2000	1995-2010	1995-2000	1995-2010
	(1)	(2)	(1)	(2)	(1)	(2)
RTC_r	1,774	3,310***	-161.8	-236.5	-0.405***	-1.002***
	(1,553)	(569.3)	(240.2)	(200.5)	(0.115)	(0.145)
R^2	0.019	0.496	0.091	0.336	0.337	0.379

Panel B. SUS Expenditures and Health Establishments	Expenditures (SIH) Hospital System		Expenditures (SIA) Outpatient System		Total Medical Esblishments	
	1995-2000	1995-2010	1995-2000	1995-2007	1992-1999	1992-2010
	(1)	(2)	(1)	(2)	(1)	(2)
RTC_r	-22.48**	-338.1***	-87.25***	-153.5***	-0.157	-3.262***
	(10.69)	(43.37)	(25.71)	(34.28)	(0.686)	(0.583)
R^2	0.455	0.455	0.415	0.340	0.462	0.573

Panel C. Capital-intensity of Healthcare Infrastructure	Hospitalization Rate		Outpatient Procedures Non-Basic / Basic Ratio		Diagnoses Rate Neoplasm Detection	
	1992-2000	1992-2010	1995-2000	1995-2007	1995-2000	1995-2005
	(1)	(2)	(1)	(2)	(1)	(2)
RTC_r	-0.222	-1.273	-2.428***	-2.030*	-10.60***	-9.514***
	(0.632)	(0.822)	(0.879)	(1.230)	(1.960)	(2.023)
R^2	0.219	0.192	0.204	0.305	0.421	0.35

Notes: The expenditure variables in Panels A and B are measured in per capita changes. Hospitalization and procedures rates, in Panel C, as well as the total medical establishments in Panel B are given by the changes of logs of the variables measured in per capita terms over the indicated period. Unit of analysis r is a micro-region. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. There are 411 micro-region observations in the estimations of Panels A and B, except for three to four missing values in government spending. In Panel C, there are 386 micro-region observations for the diagnoses rate and 411 observation for the other regressions. Observations are weighted by population. All specifications control for state-period fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

economies exhibited a proportionally higher budget allocation for healthcare services. This trend manifested in increased expenses within both the hospital and outpatient systems of SUS, as well as a relative rise in the number of healthcare establishments in the micro-regions more exposed to tariff cuts. Building on this evidence, we posit that the observed reduction in mortality rates from various diseases, including cardiovascular ailments, cancer, and other conditions, can be partially attributed to the expansion of healthcare infrastructure in these regions.

An intriguing aspect that warrants exploration is whether the expansion of healthcare infrastructure in the aforementioned regions entailed an augmentation in the complexity of available medical examinations and procedures or their capital-intensity, particularly within the context of the observed substantial reduction in mortality rates from cardiovascular diseases and neoplasms over the long term. To investigate this further, Panel C of Table 6 focuses on assessing the effects of the regional economic shock on the production outcomes within both the hospital and outpatient systems. Initially, we assess the effects of tariff cuts on the hospitalization rate per 100,000 population. Our findings reveal that the increase in the hospitalization rate in the regions most impacted by the trade liberalization shock does not exhibit statistical significance in either the medium or long term. However, the significant increase in expenditures on hospitalizations and procedures suggests a potential rise in expenditure per hospitalization, which could be indicative of the utilization of more advanced and costly methods for diagnostic and treatment purposes. Furthermore, we document significant increases in the ratio of non-basic procedures to basic procedures within the outpatient system, both in the medium and long run. These findings indicate a notable shift towards more advanced and intricate procedures within the outpatient healthcare setting.

Moreover, in an endeavor to establish a connection between the increasing complexity of medical exams and procedures and the reduction in mortality rates from cardiovascular diseases and cancer, in the last two columns of Panel C we investigate the impact of the regional economic shock on the rate of procedures aimed at diagnosing malignant tumors within the hospital system, expressed as the number of procedures per 100,000 inhabitants.[16] Our findings provide evidence indicating a substantial increase in procedures for detecting malignant neoplasms in the regions most affected by the tariff cuts. This effect is statistically significant in the medium run and retains a qualitatively similar magnitude in the longer run. It is worth emphasizing that the increase in tumor detection in the medium term may be directly linked to both the reduction in cancer mortality rates a decade following the tariff shock and, notably, the subsequent magnification of this reduction over the long term. The underlying rationale is straightforward: heightened detection of malignant tumors, particularly when associated with early detection, leads to a diminished number of deaths caused by the condition over the ensuing years.

In summary, our investigation into the potential mechanisms underlying the pro-cyclical patterns observed in mortality rates from internal causes documents, in addition to the previously outlined increases in government spending on health infrastructure, a relative rise in spending per hospitalization and hospital procedures and an upsurge in the number of non-basic procedures compared to basic procedures within the outpatient system of the Unified Health System (SUS) in regions that were more significantly impacted by the trade liberalization episode. Furthermore, our findings highlight a substantial increase in procedures aimed at detecting malignant tumors in regional economies exposed to more substantial tariff reductions. Collectively, these results provide empirical support for the hypothesis that the reduction in deaths from internal causes in the more severely affected regions can be partially attributed to the more than proportional expansion of healthcare infrastructure within these micro-regions, in comparison to areas with lower exposure to the trade-induced economic shock.[17]

[16] Regrettably, we encountered challenges in identifying hospital procedures specifically related to the detection of cardiovascular diseases that maintained consistent classification throughout the analysis period in Brazil.

[17] We assess additional channels through which the trade-induced economic shock might have impacted mortality rates from internal causes after liberalization, such as changes in air quality and the opportunity cost of medical care, in the Online Appendix.

5.3 Imports and Access to Diagnostic Machinery

Lastly, we examine the facilitation of imports of diagnostic-related machinery as a potential catalyst for the reduction in mortality rates from internal causes associated with trade liberalization. We investigate how enhanced access to foreign markets might have played a role in improving healthcare infrastructure. As alluded to previously, the years following liberalization witnessed a remarkable upswing in the prevalence of diagnostic imaging equipment across Brazil. This phenomenon prompts consideration of the plausible conjecture that the trade reform, in its essence, actively contributed to the expansion of these resources, both in terms of affordability and availability.

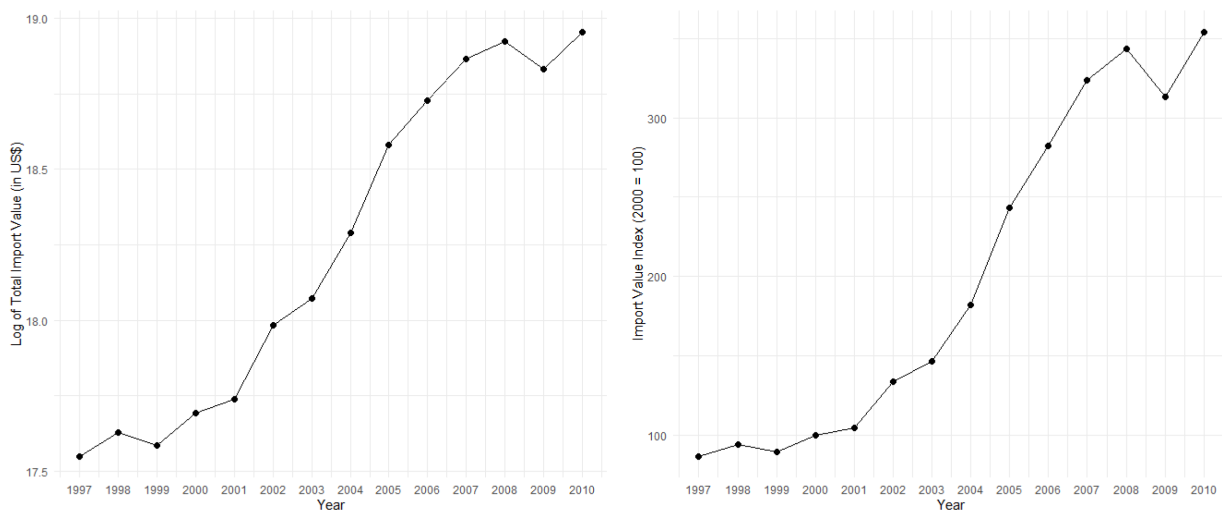
Our objective is to evaluate whether such imported diagnostic machinery influenced the decline in mortality from internal causes in regions experiencing significant tariff reductions. While one might initially expect the relative affordability of imported machinery to be uniform across the country due to the nature of the trade liberalization episode, our prior discussions underscore the disproportionate concentration of machinery expansion in regions more exposed to the trade-induced shock. Furthermore, we documented earlier that these harder-hit regions also showed a relative upswing in healthcare expenditure. Coupled with the higher pre-reform income per capita, these patterns suggest the possibility of import facilitation exerting a more accentuated impact on these particularly affected regions.

To explore this potential mechanism, we rely on detailed import data from the *Sistemas de Comércio Exterior* (SISCOMEX) provided by the Ministry of Industry, Foreign Trade, and Services. In our analysis, we specifically harness aggregated metrics detailing the total import value (measured in US dollars) of selected machinery across individual Brazilian states per annum.[18] In particular, our focus is directed towards two distinct Harmonized System header codes - 9018 and 9022 - which encompass: i) instruments and appliances utilized in medical and surgical procedures, encompassing items like scintigraphic and other electro-medical apparatus, and ii) apparatuses operating on the basis of X-rays or utilizing alpha, beta, gamma, or other ionizing radiations. These categories effectively encapsulate the selected diagnostic imaging equipment highlighted in Table 5.

Figure 5 sheds light on this mechanism by indicating the pronounced increases in total imports of selected healthcare machinery during the 2000s. Notably, panel (b) displays a growth of nearly 250% in total imports between 2000 and 2010. These discernible trends suggest that, indeed, the trade liberalization episode played a role in facilitating the influx of specific ("life-saving") machinery imports. Consequently, this exerted a direct influence on the availability of diagnostic imaging tools, a pivotal resource for the identification of cardiovascular ailments and neoplasms.

Importantly, around 70% of these imports were concentrated in the Southeast region of Brazil, where the state of *São Paulo* singularly contributed to 55% of the nation's total

[18] It is important to note that while there exists available data regarding imports at the municipality level, it is highly improbable that such finely disaggregated measures accurately represent the actual locations of machinery utilization. This is due to the fact that such goods are distributed among various micro-regions of the country after the import process.



(a) Total imports of selected machinery: Log value (b) Total imports of selected machinery: Index

Figure 5: Trends in total imports of machinery related to diagnostic: 1997-2010

Source: Brazilian foreign trade data based on the declaration of importers (SISCOMEX from the Ministry of Industry, Foreign Trade and Services).

imports within the span of ten years. This geographic concentration closely aligns with the exposure to tariff reductions during the trade liberalization episode. While the increased affordability and accessibility of machinery could theoretically have permeated broadly across the nation due to the trade reform, the marked accumulation of such equipment within the regions more exposed to the tariff cuts indicates that this mechanism actively contributed to the discernible reduction in mortality rates arising from internal causes.

6 Discussion

This paper draws inspiration from the influential work of Ruhm (2000) and subsequent literature, and investigates the effects of regional economic shocks on mortality rates in Brazil using the country's trade liberalization as a natural experiment. The findings indicate a clear pro-cyclical pattern in mortality during the analyzed periods, with regions more exposed to trade-induced economic shocks having higher reductions in mortality rates in both the medium and long run. Our baseline specification reveals that a region facing a tariff reduction reflecting a shift from the tenth to the ninetieth percentile of regional tariff changes witnessed a consequential reduction of over 10 percent in all-cause mortality rate five years post-reform and a remarkable 18 percent reduction fifteen years thereafter. These results align with previous research by Dix-Carneiro and Kovak (2017) on employment dynamics within these local economies.

Our investigation addressed concerns regarding changes in the age structure of the population by showing that the decline in mortality rates among regions exposed to the trade shock is observed across different age groups and specific causes of death. A falsification test confirms the robustness of the findings, as it demonstrates that cause-specific mortality rates unrelated to macroeconomic conditions did not show significant changes with tariff cuts. Overall, the study suggests a causal relationship between deteriorating local labor markets and mortality rates, utilizing the Brazilian trade liberalization episode as a quasi-natural experiment.

Moreover, we examined the potential mechanisms underlying the effect of the trade-induced shock on mortality rates. While we cannot pinpoint a single explanation for the mortality outcomes, we identify some explanatory channels for the reduction in mortality rates. Concerning external causes of mortality, our results are similar to Ruhm (2000) and Miller et al. (2009), pointing to the pro-cyclical nature of transport accidents and other accidents, since individuals use relatively fewer means of transport due to higher unemployment as well as practice less hazardous activities.

Importantly, we argue that that the expansion of healthcare infrastructure played a fundamental role in reducing mortality rates from internal causes in the regions more exposed to the trade-induced economic shock. The enactment of Brazil's federal Constitution in 1988 brought significant social spending increases and the establishment of the *Sistema Único de Saúde*, the world's largest publicly-funded healthcare system. The expansion of health-related government spending and decentralization of health management were observed across different regions, although the availability of medium and high-complexity exams and procedures, particularly for cardiovascular diseases and neoplasms, saw a pronounced growth in more affluent localities, coinciding geographically with the magnitude of the regional tariff shock.

We then investigated the direct impacts of the trade-induced economic shock on healthcare infrastructure indicators in the country's local economies. Our findings suggest that regions most affected by the tariff reductions experienced significant increases in the share of government spending on health and sanitation and in the number of healthcare establishments compared to regions less impacted by tariff cuts. Moreover, we find significant increases in hospitalization and outpatient expenditures, as well as potential rises in the expenditure per hospitalization and a shift towards more complex procedures within the outpatient system in these harder-hit regions. We also document a substantial increase in procedures for detecting malignant tumors in the micro-regions more impacted by the shock.

Lastly, we explore the potential role of trade reform in directly fostering the expansion of specific diagnostic imaging machinery through imports and cost reduction. Our analysis reveals a concentrated expansion of total imports of these "life-saving" or "death-minimizing" goods in regions more significantly affected by the trade-induced shock, suggesting that import-driven expansion of capital-intensive healthcare infrastructure played a role in the reduction of mortality rates stemming from internal causes.

In summary, these findings underscore the pivotal role of healthcare infrastructure in ameliorating the ramifications of economic shocks on mortality rates. Interestingly, the existence of a universal public-funded healthcare system in Brazil since the late 1980s and its expansion post-liberalization appears to mitigate fluctuations in access to capital-intensive medical care during economic downturns. The implications of these insights are profound. Policymakers should prioritize healthcare infrastructure investment, especially in vulnerable regions, to enhance health outcomes and curtail mortality rates. Furthermore, efforts aimed at enhancing healthcare management decentralization emerge as enablers of healthcare infrastructure expansion. Importantly, policymakers should account for potential health repercussions arising from trade policy shifts and adopt measures ensuring healthcare access.

By way of conclusion, it is important to highlight that there is still much to explore to fully comprehend the intricate connections between macroeconomic conditions and mortality rates in Brazil. However, this study is a relevant step in this research agenda. It not only contributes to the health economics literature by shedding light on the pro-cyclical nature of mortality but also enhances our understanding of the impacts of trade liberalization experiences worldwide. While it is important to note that our analysis captures only a partial equilibrium effect of the Brazilian trade liberalization episode, as previously pursued for instance in Dix-Carneiro et al. (2018) and Charris et al. (2023), our empirical findings provide valuable evidence that expands upon the existing literature on developing countries and can indicate an intriguing avenue for future research.

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A Appendix

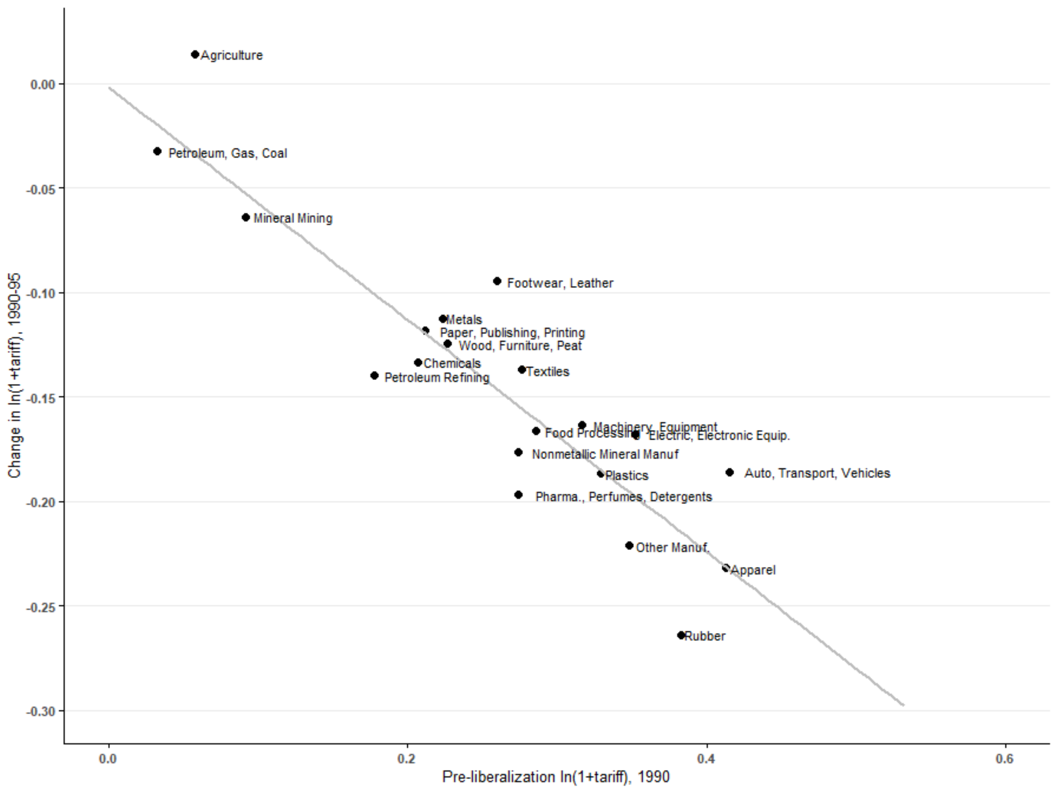


Figure A.1: Relationship between tariff changes and pre-liberalization tariff Levels

Table A.1: Definition of specific causes of mortality

Variables	Description	ICD-9 (1985-1995)	ICD-10 (1996-2010)
General	General mortality: all causes	001-E999	A00-Y99
Infant	General mortality of infants (less than 1 year old)	001-E999	A00-Y99
Endocrine	Endocrine, nutritional and metabolic diseases	240-279	E00-E89
CVD	Major cardiovascular diseases	390–448	I00–I78
Cancer	Malignant neoplasms	140–208	C00–C97
Transport	Transport accidents	800–848, 929.0, 929.1	V02–V99, Y85
Other Ac	Other (non-transport) accidents	850–928, 929.2–949	W00–X59, Y86
Medical	Misadventures to patients during surgical and medical care[a]	870-879	Y62-Y69, Y83-Y84
Falls	Accidents: falls	880–888	W00–W19
Drowning	Accidents: drowning/submersion	910	W65–W74
Fires	Accidents: smoke/fire/flames	890–899	X00–X09
Poison	Accidents: poisoning/noxious substances	850–869, 924.1	X40–X49
Suicide	Suicide (intentional self-harm)	950–959	X60–X84, Y87.0
Homicide	Homicide and legal intervention	960–978	X85–Y09, Y87.1, Y35, Y89.0
Nature	Accidents due to natural and environmental factors[b]	900-909	T63, X30-X39

[a] Including surgical and other medical procedures as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure.
[b] Including contact with venomous animals and plants to correctly crosswalk between ICD-9 and ICD-10.

Table A.2: Descriptive statistics at the micro-region level

Variables	Source	Mean	SD	Min	Max	Observations
Overall Mortality Rates						
Mortality rate (per 100,000 inhabitants) - 1985	DataSUS	556.13	183.79	17.46	1304.80	411
Mortality rate (per 100,000 inhabitants) - 1991	DataSUS	497.81	170.37	44.22	1014.97	411
Mortality rate (per 100,000 inhabitants) - 2000	DataSUS	517.06	140.22	43.85	856.56	411
Mortality rate (per 100,000 inhabitants) - 2010	DataSUS	586.71	127.53	148.87	889.09	411
Expenditure per Function - Municipality						
Expenditure - 1995 (annual, 2010 R$)	Ministry of Finance	507.91	259.19	0.00	1899.63	411
Expenditure - 2000 (annual, 2010 R$)	Ministry of Finance	930.42	2248.65	0.00	45909.62	411
Expenditure - 2010 (annual, 2010 R$)	Ministry of Finance	1112.01	326.54	0.00	3498.28	411
Expenditure H&S - 1995 (annual, 2010 R$)	Ministry of Finance	75.15	49.58	0.00	405.70	411
Expenditure H&S - 2000 (annual, 2010 R$)	Ministry of Finance	176.02	266.53	0.00	5279.31	411
Expenditure H&S - 2010 (annual, 2010 R$)	Ministry of Finance	393.13	146.88	0.00	1605.14	411
Number of Health Establishments						
Total - 1992	AMS - IBGE	40.07	14.25	6.17	103.73	411
Total - 1999	AMS - IBGE	41.97	15.14	9.96	159.14	411
Total - 2006	CNES - DataSUS	93.42	44.36	15.47	283.35	411
Total - 2010	CNES - DataSUS	118.99	55.56	20.97	327.43	411
Hospitalization Rates and Hospital Procedures						
Hospitalization Rate - 1992	SIH - DataSUS	10113.53	5080.35	1.91	29329.57	411
Hospitalization Rate - 2000	SIH - DataSUS	6846.78	2552.50	1.70	25883.81	411
Hospitalization Rate - 2010	SIH - DataSUS	5497.35	2245.28	9.66	18908.80	411
Neoplasm detection - 1995	SIH - DataSUS	2.12	3.37	0.08	51.38	386
Neoplasm detection - 2000	SIH - DataSUS	4.41	6.79	0.28	88.40	386
Neoplasm detection - 2005	SIH - DataSUS	4.14	5.39	0.11	37.80	386
Outpatient Procedures						
Basic - 1995	SIA - DataSUS	660572	338365	41097	1938314	411
Basic - 2000	SIA - DataSUS	681947	231265	13116	1965240	411
Basic - 2007	SIA - DataSUS	844912	257051	45816	1712669	411
Non-basic - 1995	SIA - DataSUS	106937	82667	1	542790	411
Non-basic - 2000	SIA - DataSUS	233076	170008	241	1484847	411
Non-basic - 2007	SIA - DataSUS	479284	441460	42211	3757104	411
Expenditure per capita - SUS sytems						
SIH - 1995	SIH - DataSUS	6.91	8.13	0.00	56.60	411
SIH - 2000	SIH - DataSUS	9.57	9.81	0.00	63.22	411
SIH - 2007	SIH - DataSUS	39.92	32.32	0.04	267.88	411
SIA - 1995	SIA - DataSUS	39.10	24.26	1.50	180.14	411
SIA - 2000	SIA - DataSUS	44.65	31.44	0.04	305.45	411
SIA - 2007	SIA - DataSUS	41.79	45.05	1.70	610.60	411

B Online Appendix

B.1 Robustness to Alternative Inference Procedures

In this section, we show that our baseline results are very similar if we use the inference procedures proposed by Borusyak et al. (2022), which address cross-region correlation in residuals in shift-share designs. Table B.1 indicates that our baseline results, presented in the first four columns of Table 1, are not altered when following alternative inference procedures.

Table B.1: Regional tariff changes and log changes in mortality rates (Borusyak et al. (2022) robust standard errors)

	Unweighted		Observations weighted by population		+ State fixed effects		+ Pre-trend	
	(1)		(2)		(3)		(4)	
Dep. var: $\Delta log(MR_i)$	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010
All								
RTC_i	1.593***	3.128***	1.155***	2.525***	1.079***	1.952***	1.078***	1.952***
	[0.0877]	[0.153]	[0.0325]	[0.0539]	[0.0444]	[0.0460]	[0.0464]	[0.0389]
Male								
RTC_i	1.430***	3.359***	1.058***	2.930***	1.082***	2.117***	1.036***	2.062***
	[0.0868]	[0.163]	[0.0297]	[0.0682]	[0.0476]	[0.0568]	[0.0479]	[0.0463]
Female								
RTC_i	1.844***	2.805***	1.313***	2.014***	1.109***	1.758***	1.165***	1.844***
	[0.0956]	[0.148]	[0.0424]	[0.0689]	[0.0462]	[0.0530]	[0.0499]	[0.0529]

Notes: This table presents an alternative approach to inference on the baseline results from columns 1 to 4 in Table 1. There are 20 industry observations in each regression (industry-level regressions). Borusyak et al. (2022) robust standard errors are reported in brackets. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

This suggests that, in practice, much of the relevant cross-area correlation in residuals occurs within states. It is worth mentioning that this robustness of the results to potential cross-region correlation in the residuals is also observed in Charris et al. (2023).

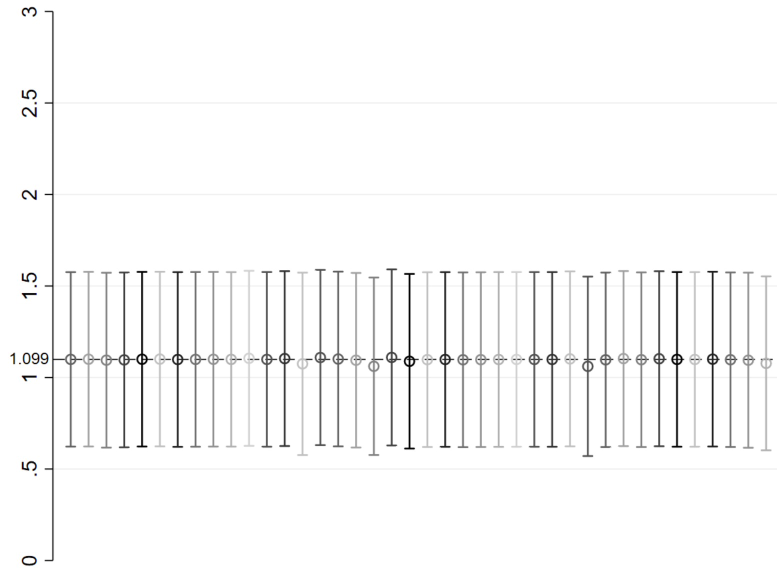
B.2 Sensitivity Analysis

To further evaluate the robustness of our baseline results, presented in Table 1, we perform a simple sensitivity analysis for the coefficients associated with the impacts of the regional tariff change on the all-cause mortality rates.

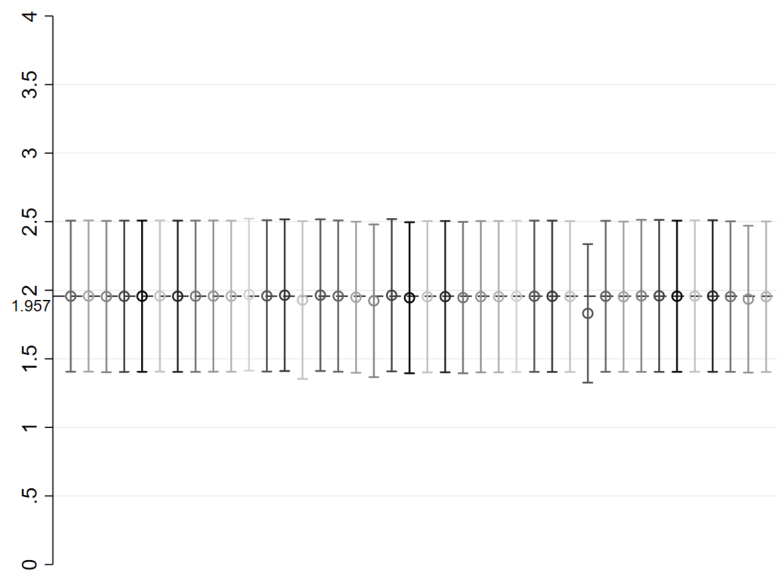
First, we estimated the preferred specification - weighted observations and with the inclusion of fixed effects - by removing, in each regression, one of the top 40 micro-regions in terms of i) the magnitude of the trade-induced, and ii) the number of obits in 1991.

Figures B.1 and B.2 graphically present the results of the estimations removing the top-ranked micro-region in terms of RTC_c and total death in 1991 respectively, emphasizing the coefficient of interest and the 95% confidence interval for each one of the regressions. We start from the highest RTC_r or number of deaths in 1991 on the left. The dotted black line describes the coefficient obtained in our baseline regression.

Similarly, Figures B.3 and B.4 present the results of estimation removing the lowest-ranked micro-region in terms of the trade-induced shock and total deaths in 1991 respectively. Notice that both qualitatively and quantitatively the additional results are very close to the estimation presented in the paper.



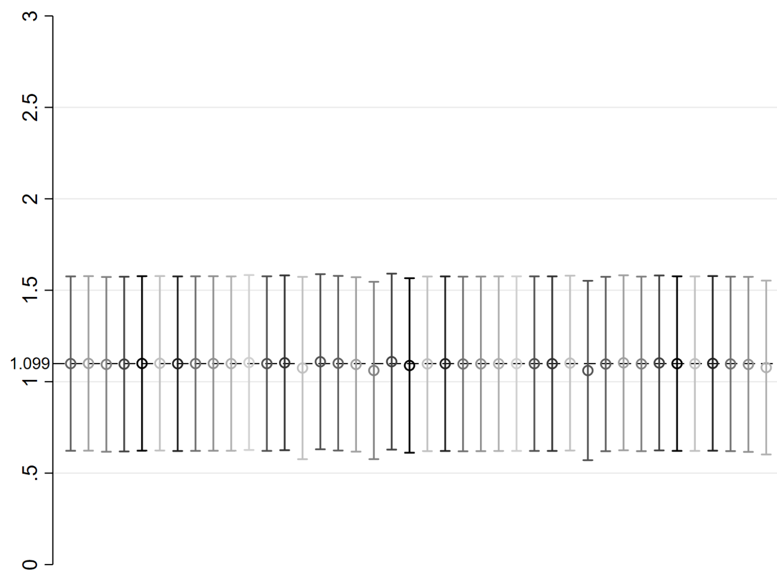
(a) 1991-2000 differences



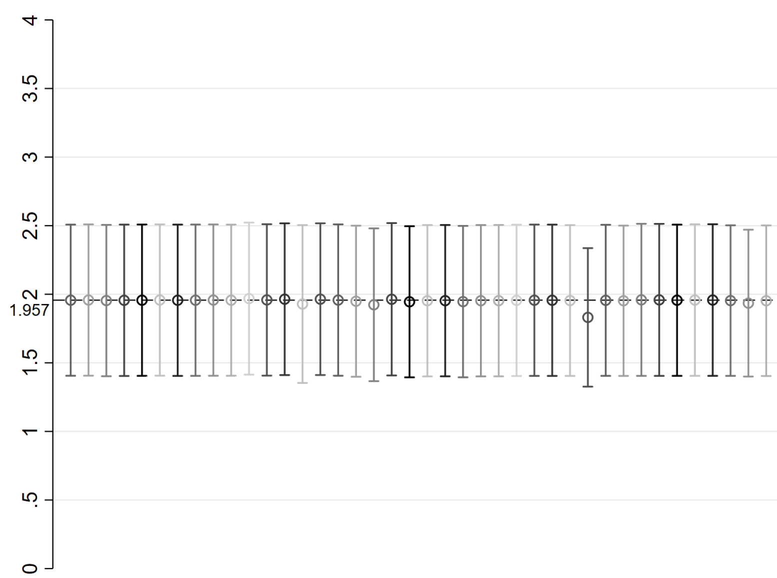
(b) 1991-2010 differences

Figure B.1: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions - Top 40 based on RTC_r value)

Notes: The figure shows the robustness of the results to excluding, one by one, the top 40 micro-regions with the highest RTC_r. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, higher RTC_r exposure is the first observation.



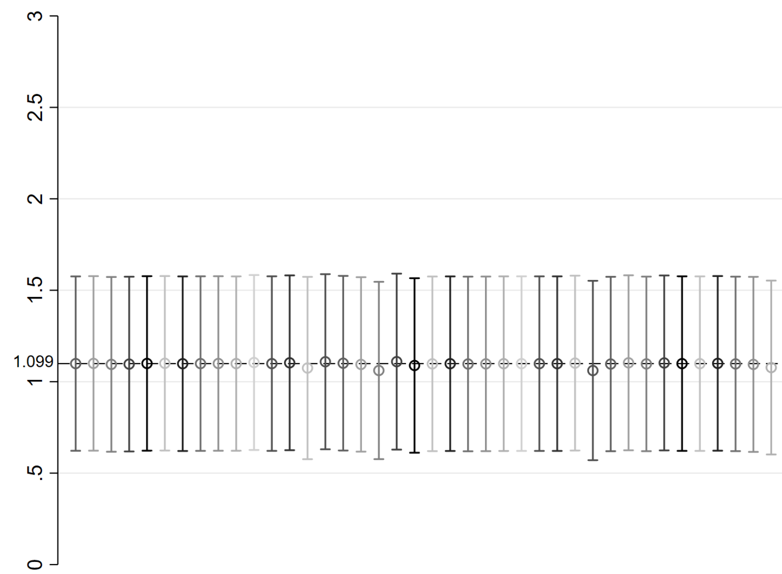
(a) 1991-2000 differences



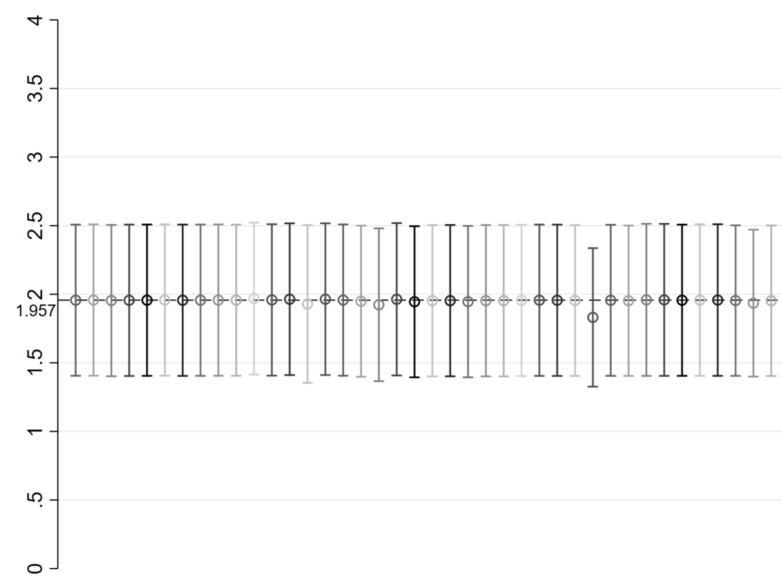
(b) 1991-2010 differences

Figure B.2: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions - Top 40 based on obits in 1991)

Notes: The figure shows the robustness of the results to excluding, one by one, the top 40 micro-regions with the highest number of deaths in 1991. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, the first coefficient on the left is associated with the micro-region with the largest number of obits in 1991.



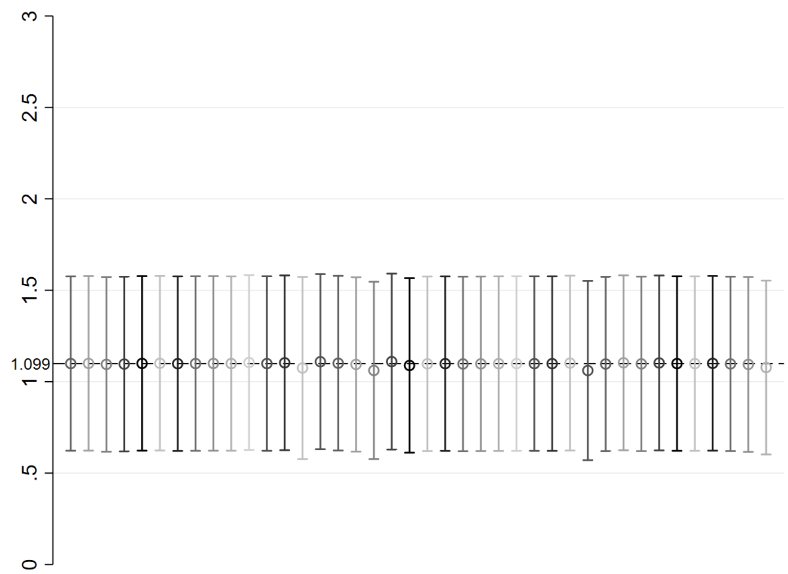
(a) 1991-2000 differences



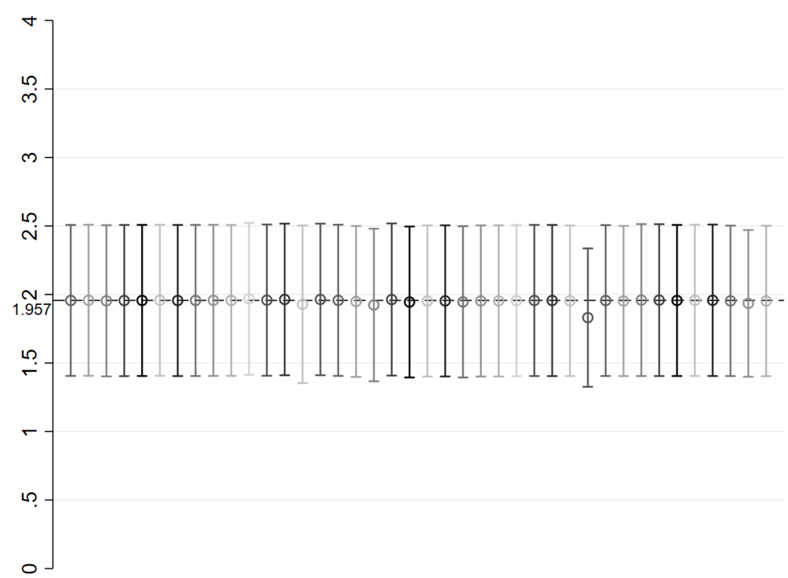
(b) 1991-2010 differences

Figure B.3: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions - Last 40 based on RTC_r value)

Notes: The figure shows the robustness of the results to excluding, one by one, the last 40 micro-regions with the lowest RTC_r. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, the lowest RTC_r exposure is the first observation.



(a) 1991-2000 differences



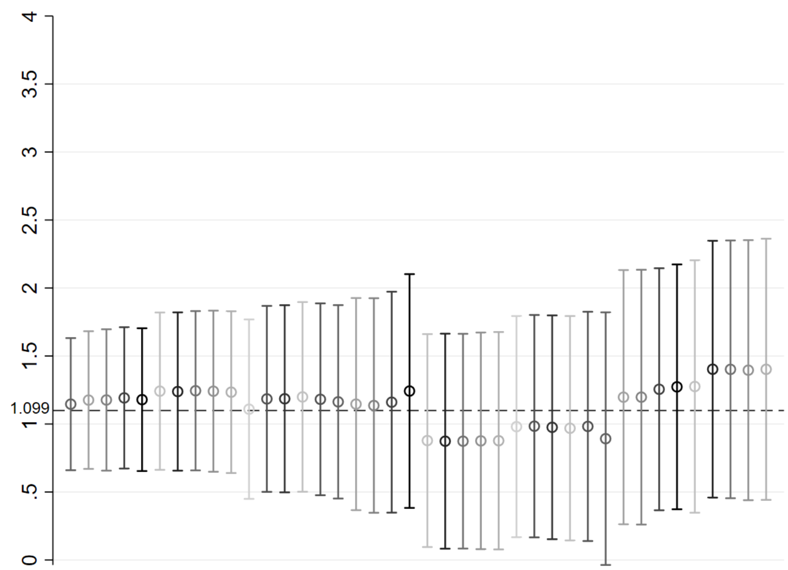
(b) 1991-2010 differences

Figure B.4: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions - Last 40 based on obits in 1991)

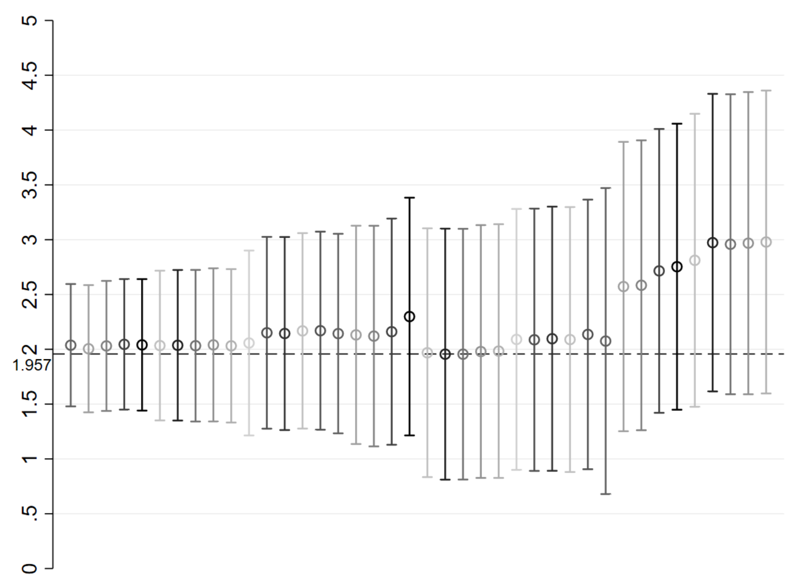
Notes: The figure shows the robustness of the results to excluding, one by one, the last 40 micro-regions with the lowest number of deaths in 1991. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from left to right - that is, the first coefficient on the left is associated with the micro-region with the lowest number of obits in 1991.

Next, we perform a similar sensitivity analysis, but now we drop the top-ranked micro-regions following the same criteria one to many. That is, we sequentially drop the top-ranked local economies from the estimation up to roughly 10% of our total sample (40 micro-regions). Figures B.5 and B.6 present, respectively, the results for excluding regions classified by RTC_r and total deaths in 1991. Again, we emphasize the coefficient of interest and the 95% confidence interval for each one of the regressions. We start from the highest RTC_r or number of deaths in 1991 on the left. The dotted black line describes the coefficient obtained in our baseline regression.

Similarly, Figures B.7 and B.8 present, respectively, the results for excluding regions classified from the lowest exposure to the trade-induced economic shock and total deaths in 1991.



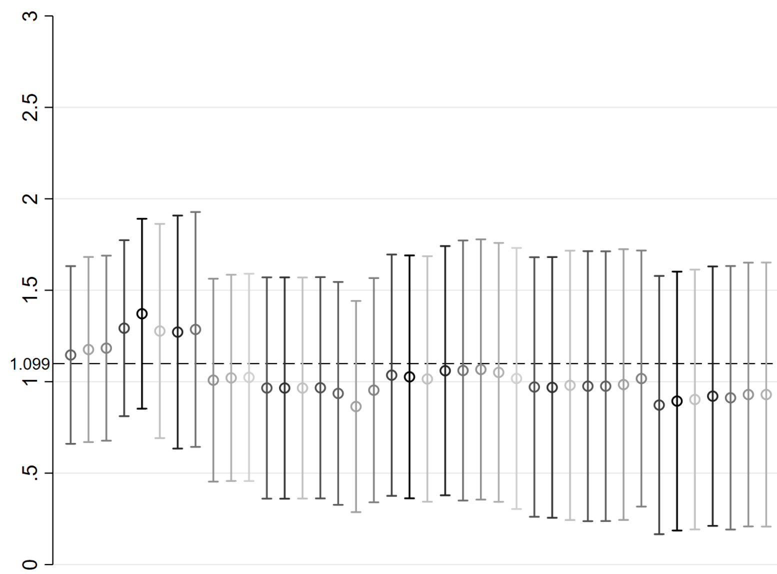
(a) 1991-2000 differences



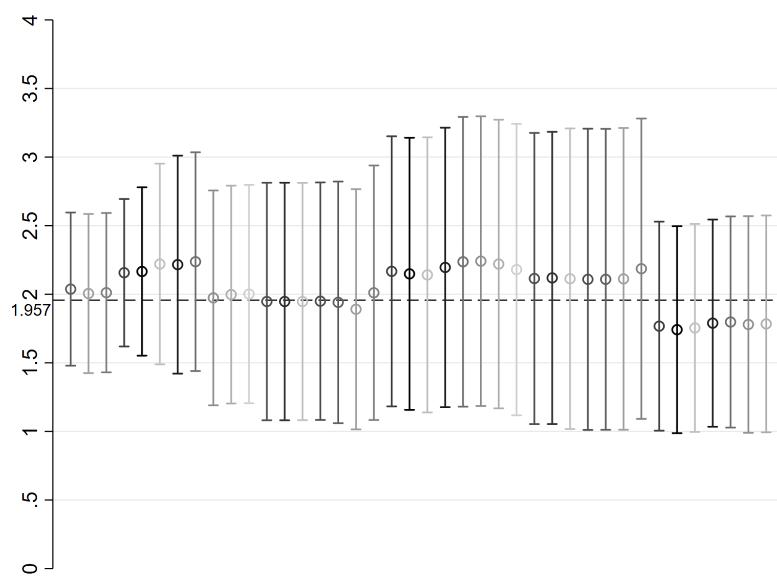
(b) 1991-2010 differences

Figure B.5: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions one to many - Top 40 based on RTC_r value)

Notes: The figure shows the robustness of the results to excluding the top 40 micro-regions with the highest RTC_r. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, higher RTC_r exposure is the first observation.



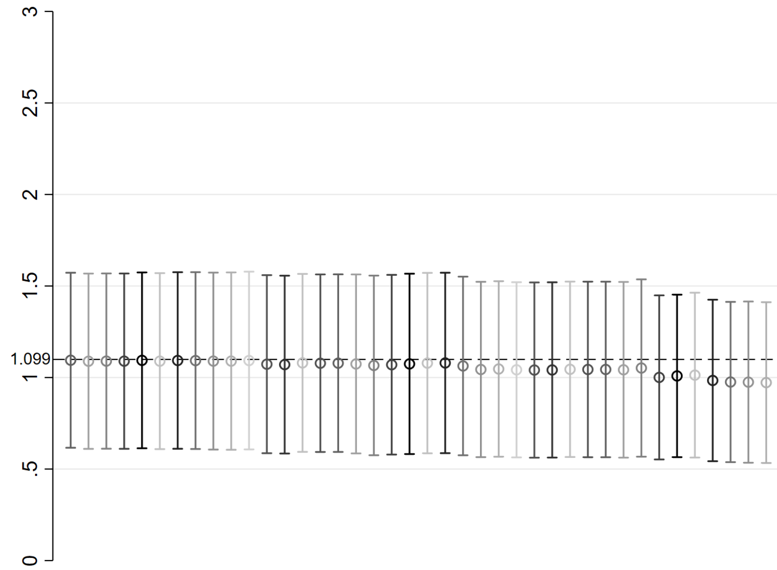
(a) 1991-2000 differences



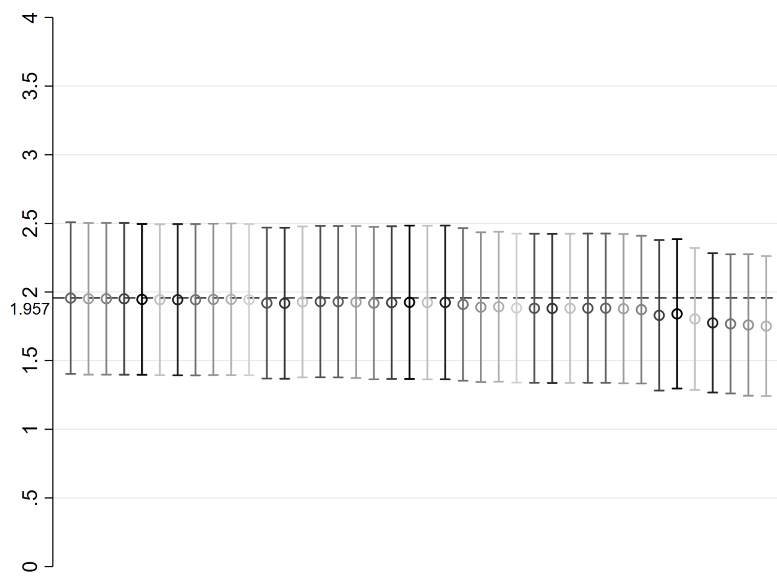
(b) 1991-2010 differences

Figure B.6: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions one to many - Top 40 based on obits in 1991)

Notes: The figure shows the robustness of the results to excluding the top 40 micro-regions with the highest number of deaths in 1991. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, the first coefficient on the left is associated with the micro-region with the largest number of obits in 1991.



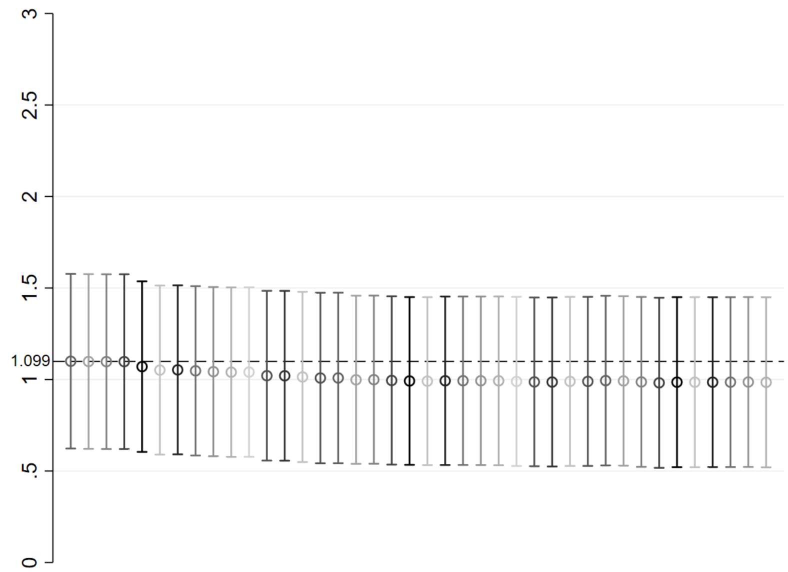
(a) 1991-2000 differences



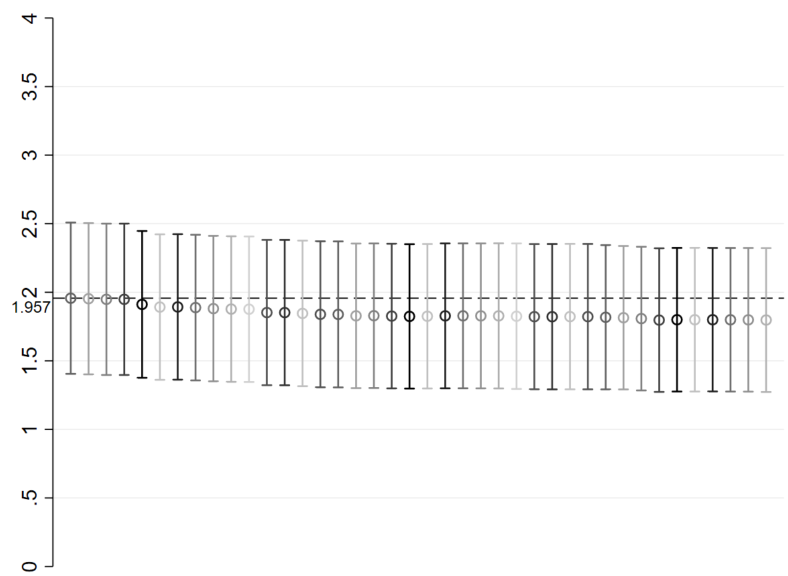
(b) 1991-2010 differences

Figure B.7: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions one to many - Last 40 based on RTC_r value)

Notes: The figure shows the robustness of the results to excluding the last 40 micro-regions with the lowest RTC_r. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, the lowest RTC_r exposure is the first observation.



(a) 1991-2000 differences



(b) 1991-2010 differences

Figure B.8: Regional tariff change and log-changes in all-cause mortality rate (Exclusion of micro-regions one to many - Last 40 based on obits in 1991)

Notes: The figure shows the robustness of the results to excluding the last 40 micro-regions with the lowest number of deaths in 1991. The estimated coefficients and confidence intervals at 95 percent are reported. Each estimated coefficient and confidence interval emanate from a single estimation. Micro-regions ranked from the left to the right - that is, the first coefficient on the left is associated with the micro-region with the lowest number of obits in 1991.

B.3 Transport and Other Accidents

Table B.2 presents the complete set of regressions for both transport and other accidents.

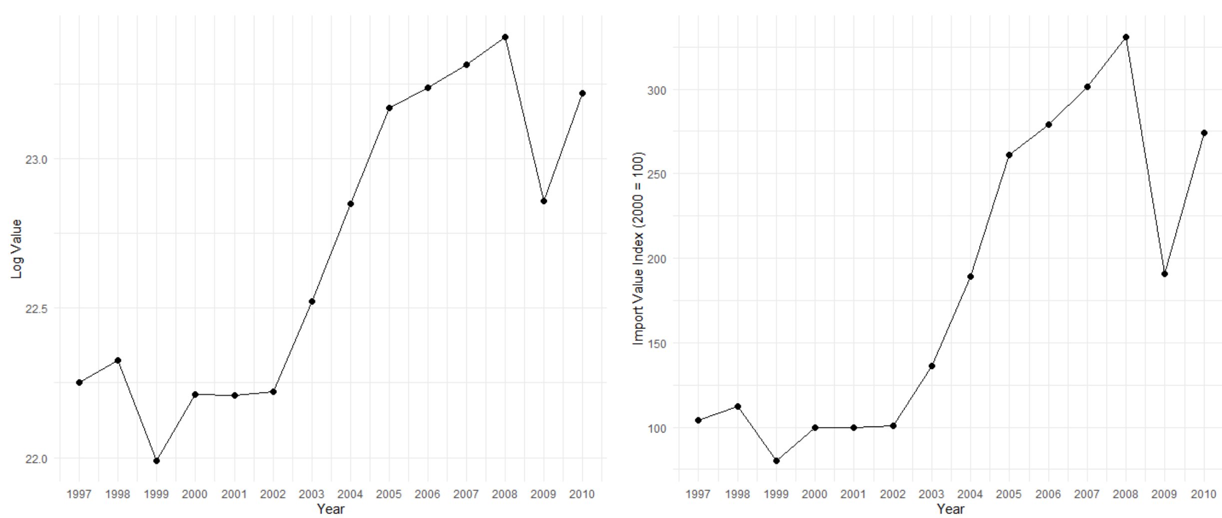
Table B.2: Regional tariff changes and log changes in accident-related mortality rates

	OLS (1)		OLS (2)		OLS (3)		OLS (4)		2SLS (5)		Placebo (6)
Dep. var.: $\Delta log(MR_r)$	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1985-1991
Transport Accidents											
RTC_r	5.992***	11.11***	6.774***	10.26***	5.950***	8.093***	6.170***	8.433***	5.874***	8.055***	0.633
	(0.771)	(0.944)	(1.227)	(0.907)	(1.080)	(1.671)	(0.788)	(0.948)	(0.839)	(1.112)	(1.568)
$\Delta_{85-91}log(MR_r)$							-0.349***	-0.559***	-0.158*	-0.336***	
							(0.046)	(0.065)	(0.089)	(0.110)	
Other Accidents											
RTC_r	3.661***	6.820***	1.935***	3.771***	3.033***	4.705***	2.622***	4.320***	2.912***	4.605***	-0.866
	(0.886)	(0.960)	(0.863)	(1.340)	(1.015)	(1.123)	(0.901)	(1.056)	(0.948)	(1.082)	(0.701)
$\Delta_{85-91}log(MR_r)$							-0.488***	-0.458***	-0.138	-0.0056	
							(0.082)	(0.079)	(0.101)	(0.111)	

Notes: There are 411 micro-region observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. Unit of analysis r is a micro-region. In column 1, observations are not weighted; in column 2, observations are weighted by population;column 3 adds state fixed effects to column 2; column 4 adds pre-trends to column 3; column 5 shows two-stage least squares, with an instrument for $\Delta_{85-91}log(MR_r)$. Column 6 presents a placebo test, with observations weighted by population and considering state fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

B.4 Imports of Automotive Vehicles and Parts

Figure B.9 describes the pronounced increase in imports of automotive vehicles and their parts in Brazil during the 2000s.



(a) Total imports of vehicles and parts: Log value

(b) Total imports of vehicles and parts: Index

Figure B.9: Trends in total imports of vehicles and parts: 1997-2010

Source: Brazilian foreign trade data based on the declaration of importers (SISCOMEX from the Ministry of Industry, Foreign Trade and Services) - Chapter 87 in the Harmonized System.

B.5 Air Pollution

In this section, we assess the potential impact of the regional tariff changes on air quality. Extensive research has shown a strong association between air pollution and adverse health outcomes, particularly increased mortality risks from cardiovascular and respiratory diseases (Clancy et al., 2002; Graff Zivin & Neidell, 2013; Heutel & Ruhm, 2016; Mustafić et al., 2012). Infants are particularly vulnerable to the effects of air pollution, and numerous studies have documented its impact on infant mortality (Arceo et al., 2016; Chay & Greenstone, 2003; Currie & Neidell, 2005; Currie et al., 2009, 2014; Knittel et al., 2016).[19]

While the existing literature regarding the effect of air quality on the pro-cyclical nature of overall mortality rates is relatively limited, a noteworthy exception is the study conducted by Heutel and Ruhm (2016), which identifies a significant positive correlation between pollution concentrations and overall mortality rates. Their research demonstrates that controlling for carbon monoxide, particulate matter, and ozone considerably weakens the relationship between overall mortality and the unemployment rate.

Motivated by these insights, we proceed to examine the impact of the regional tariff shock on air quality in the local economies of Brazil, with a specific focus on the concentration of particulate matter. We employ data on global air pollutant estimates, specifically particulate matter (PM_{10}), from the Emissions Database for Global Atmospheric Research (EDGAR). We construct municipality-year concentration levels of PM_{10}, aggregating up from grid-level estimates to examine the potential role of air pollution in explaining the observed mortality patterns. Our analysis involves estimating Equation (2), utilizing the log changes in PM_{10} during the periods of 1991-2000 and 1991-2010 as dependent variables. Table B.3 summarizes our results.

[19] However, it is worth mentioning that Charris et al. (2023) only find a minimal impact of tariff cuts on carbon monoxide emissions two decades after liberalization, suggesting that air quality may have played a minor role in reducing infant mortality in the regions more exposed to the trade-induced economic shock.

Table B.3: Other factors

Panel A. Air pollution	PM_{10}		
	1991-2000	1991-2010	Placebo 1985-1991
	(1)	(2)	(3)
RTC_r	0.817***	1.298***	0.0148
	(0.173)	(0.401)	(0.300)
R^2	0.282	0.279	0.422

Notes: Data from the Emissions Database for Global Atmospheric Research (EDGAR). All left-hand-side variables are given by the changes of logs over the indicated period. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. Unit of analysis r is a micro-region. There are 411 micro-region observation. Observations are weighted by population. All specifications control for state-period fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

We find statistically significant reductions in particulate matter concentration both in the medium and long term, although the estimated effects have very limited magnitudes. A decrease of -0.1 log points in RTC_r corresponds to an approximately 0.8% reduction in particulate matter between 1991 and 2000. The influence of trade-induced economic shock on air quality shows a slight increase over time, as shown in column 2. In short, while improvements in air quality seem to contribute to the effects of trade-induced economic shock on mortality rates from internal causes, the evidence suggests that these effects are relatively modest and not the primary driving force behind the overall impacts.

B.6 Opportunity Cost of Medical Care

Lastly, we turn our attention to another potential mechanism identified in the health economics literature: the opportunity cost of engaging in health-improving activities. Ruhm (2000) proposes that during periods of economic expansion, leisure time decreases, leading to a rise in the opportunity cost of engaging in activities such as physical exercise. Ruhm (2005) provides empirical evidence supporting this mechanism. Unfortunately, data specifically pertaining to this mechanism in Brazil during the period of interest are not available. However, we posit that the logic of opportunity cost of time may play a role in health care utilization within the Brazilian context.

In Brazil, where healthcare coverage is nearly universal, the influence of employer-provided insurance or coverage rates on healthcare utilization during economic downturns is not as pronounced.[20] Instead, the cost of health care utilization is primarily associated with the time required to schedule medical appointments and procedures. While specific municipality-level data on healthcare utilization are lacking for the early 1990s, we utilize mortality rates

[20]This mechanism is explored, for instance, in Ruhm (2003) and Lang et al. (2019) in the US context.

from medical complications as a proxy for the demand for medical care. Intuitively, if the demand for medical care and surgical procedures increases during economic downturns, due to a lower opportunity cost, we expect an increase in medical care-related mortality. Our findings, summarized in Table B.4, suggest that medical care-related mortality rates increased in the regions more exposed to the tariff cuts, partially supporting the notion of higher healthcare utilization in the local economies more negatively impacted by the liberalization episode.

Table B.4: Regional Tariff Changes and log changes in "medical" mortality rates

	OLS (1)		OLS (2)		OLS (3)		OLS (4)		2SLS (5)		Placebo (6)
Dep. var.: $\Delta log(MMR_r)$	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1991-2000	1991-2010	1985-1991
RTC_r	-3.257***	-1.279	-2.930*	-3.083	-6.520***	-4.389**	-7.162***	-4.768**	-6.075***	-4.189**	-1.668
	(0.944)	(1.281)	(1.624)	(2.018)	(1.543)	(2.126)	(1.613)	(2.070)	(1.558)	(2.001)	(1.316)
$\Delta_{85-91} log(MR_r)$							-0.383***	-0.225**	0.265	0.119	
							(0.121)	(0.107)	(0.301)	(0.208)	

Notes: There are 408 micro-region - the unit of analysis - observations. Standard errors (in parentheses) are adjusted for 91 meso-region clusters. In column 1, observations are not weighted; in column 2, observations are weighted by population;column 3 adds state fixed effects to column 2; column 4 adds pre-trends to column 3; column 5 shows two-stage least squares, with an instrument for $\Delta_{85-91} log(MMR_r)$. Column 6 presents a placebo test, with observations weighted by population and considering state fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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