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AVOIDABLE ENVIRONMENTAL DISASTERS AND INFANT HEALTH: EVIDENCE FROM A MINING DAM COLLAPSE IN BRAZIL

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Avoidable environmental disasters and infant health: Evidence from a mining dam collapse in Brazil

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ABSTRACT

We study the health consequences of one of the largest environmental disasters of the world mining industry, which largely stemmed from regulatory failure. Exploiting the timing and location of the Mariana mine tailings dam collapse in Brazil, we show that in utero exposure to the tragedy significantly reduced birth weight and increased infant mortality. The adverse effects were stronger for infants born to less educated and single mothers. These findings indicate that poorly enforced environmental regulation may have long-term welfare impacts on local communities.

JEL Classification: I18, I15, J13, Q50.

Keywords: Birth weight; Preventable disasters; Mining; In utero exposure.

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1 Introduction

In many developed and developing countries, mineral production plays a critical role in local economic performance and government revenue. This prominent role has given rise to debates about how the sector should be regulated to minimize its environmental impacts, and in particular to avoid environmental disasters from technical failures — such as reoccurring tailings dam disasters. Unlike natural disasters, including floods and earthquakes, most tailings dam failures are preventable and largely the result of poor regulatory enforcement. In a recent report, the United Nations Environment Program stresses that:

> "Tailings Dam failures are ... caused as much by regulatory as management failure. ... The regulatory system has failed to ensure good design, and to implement, monitor and enforce adequate standards. Regulatory systems with multiple, independent checks are required to ensure standards and detect impending failures" (UNEP, 2017, p. 60).

Tailings dam incidents generally release contaminants and toxic wastes that are known to be hazardous to health. Yet we lack a good understanding of the health and other consequences of these regulatory failures. Such estimates are crucial for the optimal design of environmental regulation policies, and for evaluating the overall welfare impacts of mineral production in developing countries.

In this paper, we provide the first evidence on the infant health consequences of tailings dam incidents by examining the Mariana failure in Brazil, one of the largest tailings disasters registered to date. Given the importance of infant health in subsequent human capital accumulation (Figlio et al., 2014; Black, Devereux and Salvanes, 2007), these results may have important intergenerational implications and influence the debate on the benefits of implementing costly environmental regulatory policies.[1]

1.1 The Mariana mine tailing disaster

On November 5, 2015, a large dam containing 52 million cubic meters of iron mining residues (tailings) collapsed in Mariana, located in the state of Minas Gerais (MG), Brazil (see Figure A.1). As a mudwave flowed through a narrow valley and quickly reached the locality of Bento Rodrigues, it destroyed several buildings and killed 19 people. The mudflow traveled further downstream, affecting wildlife, vegetation and other settlements before reaching Rio Doce, a river that flows eastward to the Atlantic Ocean. This collapse is considered the largest environmental disaster in Brazil and the largest in the world involving tailings dams.

The environmental and socioeconomic consequences of the disaster were highly publicized. Hundreds of houses were destroyed; water supply and sanitation systems were interrupted in many cities, leaving thousands of people facing serious water shortages. The disaster also destroyed hydroelectric power plants and infrastructures, compromising regional trade, tourism and other activities, causing a massive job loss in the region. Entire fish populations were immediately killed (UNEP, 2017).

[1]Another large tailings dam failure happened (three years after the Mariana disaster) in Brumadinho, which killed more than 240 people.

Communities were affected in many ways, with more than 1 million inhabitants in 39 municipalities throughout 600 kilometers being exposed to the mud. Such a destructive shock affects all individuals, including pregnant women.

2 Data and empirical strategy

We use publicly available birth registry data provided by the System of Information on Live Births (SINASC) from 2011 to 2016. These data include information about the pregnancy (birth weight, gestational length) and the mother (age, education, marital status, municipality of residence). More importantly, it provides the date of the last menstrual period, which in this study is considered the date of conception.

Our treated group consists of women living in municipalities affected by the disaster who were exposed to the tragedy during their pregnancy. We assign the trimester of exposure based on each 93-day window ([0,3] months, (3,6] months, (6,9] months) since conception date, irrespective of gestational length.[2] Due to endogenous fertility and selective migration after the disaster, we limit our analysis to mothers who made their fertility decisions before the event.

To construct the comparison group, we exploit the fact that there are other dams located in the same state, built in the same years and with similar technology as the Mariana dam.[3] We simulate the mud path for all such dams as if they had suffered a similar failure. Our baseline comparison group is composed of pregnant women living in the five most affected municipalities in each simulated dam failure.[4]

Our empirical strategy exploits the timing and location of the Mariana dam collapse to identify the impact of *in utero* exposure to the disaster on birth outcomes. We estimate the following difference-in-differences (DID) specification:

$$Y_{imts} = \beta \cdot \mathbf{exposure}_{imts} + X'_{imts}\Theta + \omega_m + \lambda_t + \mu_s + \varepsilon_{imts} \qquad (1)$$

where Y_{imts} is an outcome observed for child i, conceived in month m and year t, with a mother residing in municipality s, and X_{imts} is a vector of controls. The municipality fixed effect μ_s accounts for unobserved time-invariant determinants of birth outcomes shared among mothers residing in the same municipality, while the inclusion of month and year fixed effects, ω_m and λ_t, adjusts for shocks that are common to all pregnant women at a specific moment in time. The indicator variable **exposure** equals one for women exposed to the disaster during their pregnancy and zero for pregnant women in the comparison group. The key parameter of interest is then β, which measures whether infants exposed to the disaster during the gestational period have worse outcomes.

We also analyze trimester-specific impacts of the disaster by flexibly allowing the effect of exposure to vary by trimester of pregnancy. We estimate the following event-study

[2] This treatment definition, in contrast to using birth dates to measure exposure, avoids problems that can arise if the gestational duration is affected by the disaster.

[3] This information comes from *Agência Nacional de Mineração*. Available at https://bit.ly/2MADO0b.

[4] We exclude municipalities in urban agglomerations, outside the state of MG, and those belonging to the simulated mud paths that were also affected by the Mariana disaster. In the appendix we show that our results are robust under several control group definitions.

specification:

$$Y_{imts} = \left[\sum_{\tau=-15}^{-2} \beta_\tau I(t_{mts} - t^* = \tau) + \sum_{\tau=0}^{2} \beta_\tau I(t_{mts} - t^* = \tau) \right] + X'_{imts}\Theta + \omega_m + \lambda_t + \mu_s + \varepsilon_{imts} \quad (2)$$

where the indicator $I(t_{mts} - t^* = \tau)$ measures the time (in trimesters) relative to the day of the collapse, t^*. We set the coefficient on β_{-1} equal to zero to use the trimester immediately prior to the disaster as the reference. If prenatal exposure to the disaster in the third (β_0), second (β_1) or first trimester (β_2) has adverse consequences on birth outcomes, one would expect the relevant coefficients to be negative and significant.

Our primary identifying assumption is that children born to mothers living in municipalities exposed to the disaster during their gestational duration would have had similar trends in birth outcomes as those living in similar municipalities outside of the affected area in the absence of the shock.

3 Results

We begin by plotting in Figure 1 the event-study estimates for the relationship between birth weight, infant mortality and the disaster date. Birth weight and infant mortality in affected and control groups evolved similarly during the period prior to the tailings dam collapse. This suggests the absence of different pre-trends and yields support for the main identifying assumption. After the disaster, we document a sharp decline in birth weight and an increase in infant mortality for children exposed *in utero*, especially among those exposed in the third trimester of pregnancy.

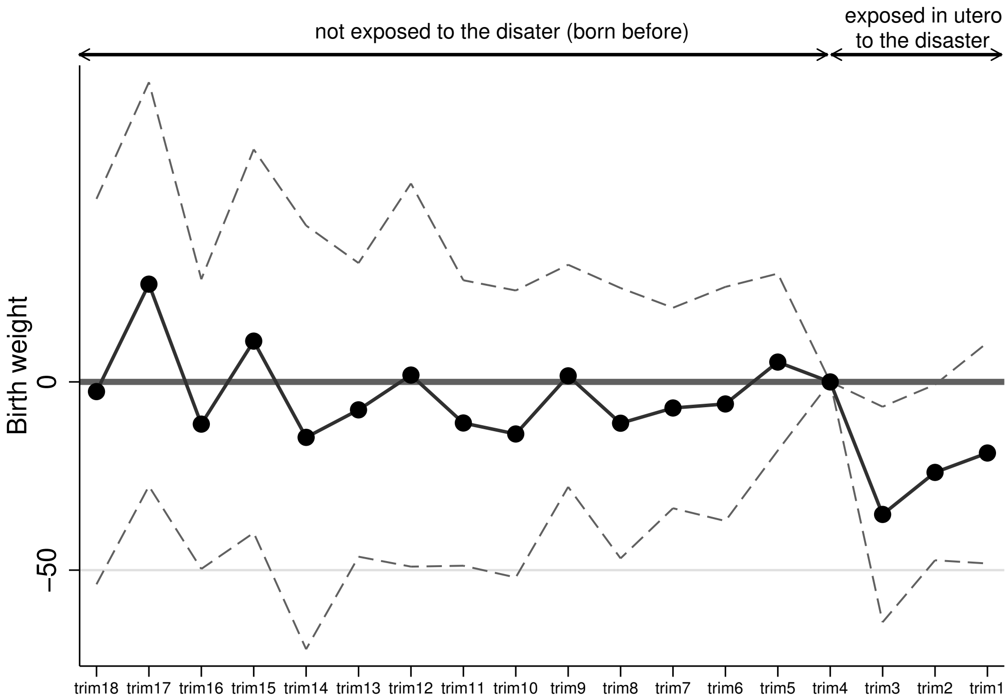
Table 1 reports the results. We find that exposure to the disaster during pregnancy is associated with detrimental effects on birth weight (columns 1–6). There is a reduction of 23-24 grams in the birth weight among children exposed *in utero* to the dam collapse.[5] In columns 4–6 we allow the estimated effects to vary by trimester of the pregnancy. Coefficients are more precisely estimated for those exposed in the third trimester. Results are similar across specifications when we include only municipality, month, and year of conception fixed effects (without the control variables as in our main specification), or when we include month×year of conception fixed effects.

In columns 7–8 we investigate if a reduction in birth weight is the result of the disaster's direct impact on gestational duration. Birth weight will reduce if gestational length responds to the stress caused by the event. We do not find an effect of exposure on the number of gestational weeks. Finally, columns 9–10 present estimates of the effect of the disaster on infant mortality. We find strong evidence that the event led to increases in infant death.

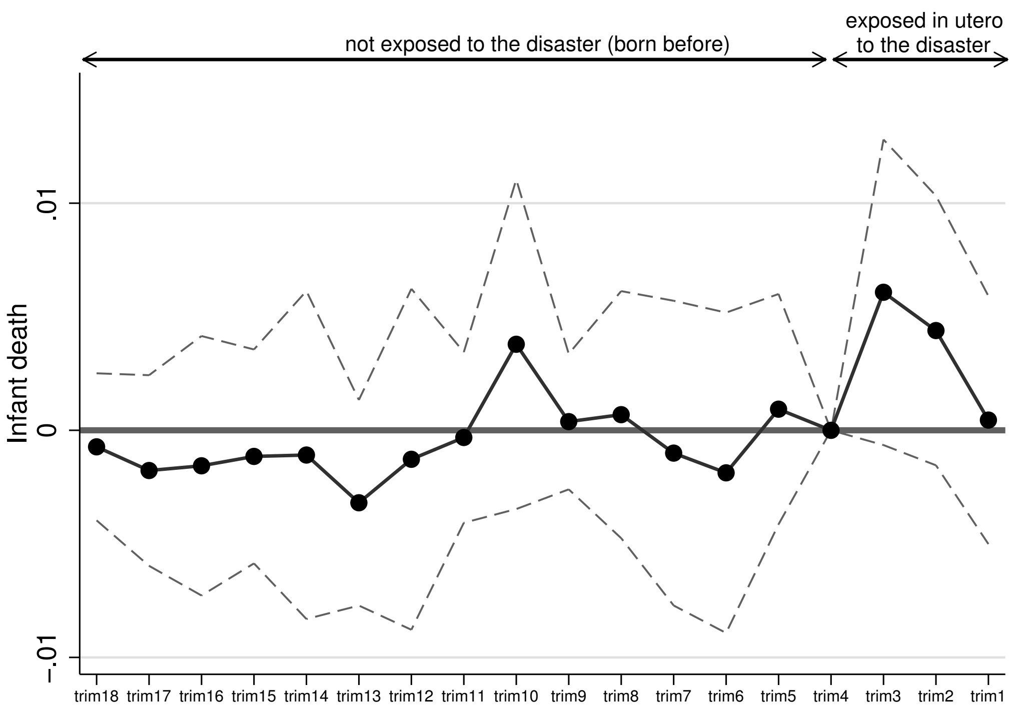
[5] Camacho (2008), for instance, finds that living near a landmine explosion during pregnancy reduces birth weight by nine grams.

Figure 1: Event-Studies: Effects of the dam incident on birth weight and infant mortality

(a) Birth weight



(b) Infant mortality



Notes. This figure plots the coefficients of Equation (2). The trimester immediately prior to the disaster (trim4) is used as the reference period. Dashed lines show 95 percent confidence intervals.

Table 1: Effects of exposure on birth weight, weeks of gestation and mortality

	Birth weight						Weeks of gestation		Infant death	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Exposure (any trimester)	-24.029	-23.562	-23.790				-0.022		0.004	
	[12.761]*	[13.591]*	[14.066]*				[0.047]		[0.001]***	
3^{rd}trim.				-30.689	-32.360	-29.031		-0.062		0.007
				[8.426]***	[9.669]***	[12.827]**		[0.058]		[0.002]***
2^{nd}trim.				-21.370	-19.698	-28.384		-0.019		0.005
				[16.201]	[16.729]	[19.516]		[0.058]		[0.001]***
1^{st}trim.				-20.162	-18.856	-13.788		0.014		0.001
				[19.950]	[20.217]	[21.899]		[0.059]		[0.002]
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month and year of conception FE	Yes	Yes		Yes	Yes		Yes	Yes	Yes	Yes
Control variables		Yes			Yes		Yes	Yes	Yes	Yes
Month×year of conception FE			Yes			Yes				
Number of obs.	100,704	96,089	100,704	100,704	96,089	100,704	96,089	96,089	96,089	96,089
R^2	0.007	0.020	0.008	0.007	0.020	0.008	0.011	0.011	0.003	0.003

Notes. Because of space constraints, we do not report coefficients for trimesters prior to the collapse. Control variables are: indicator for married mothers, newborn sex, high-education mothers (12 or more years of schooling), and dummies for mothers older than age 40 and younger than age 20. Standard errors clustered at the municipal level. ***p<0.01, **p<0.05, *p<0.1.

Heterogeneous effects. In Table 2 we split the sample by mother's education, marital status and age to investigate whether disadvantaged mothers are more affected by the disaster. We find that less educated mothers are largely affected if exposed to the disaster during the third trimester. For more educated mothers, the effect is quantitatively close to zero, irrespective of the trimester of pregnancy when exposed. We find weak evidence that married mothers are affected, while single mothers are significantly affected when exposed during the third trimester of pregnancy. Regarding age, we find statistically significant effects only for mothers age 20 or older, although coefficient estimates are larger but imprecisely estimated for younger women.

Table 2: Heterogeneous effects

	Dependent variable: Birth weight											
	Mother's education				Married				Mother's age			
	More than 12 years		Less than 12 years		Yes		No		Younger than age 20		Older than age 20	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Exposure (any trim.)	-9.351		-27.796		-18.809		-30.217		-7.416		-26.346	
	[17.633]		[15.198]*		[14.403]		[15.815]*		[25.732]		[14.051]*	
3^{rd}trim.		1.698		-40.984		-5.240		-65.533		-45.922		-27.974
		[31.361]		[11.893]***		[17.529]		[24.649]***		[38.844]		[12.339]**
2^{nd}trim.		3.907		-26.034		-19.687		-20.857		-32.468		-16.851
		[26.428]		[22.818]		[12.908]		[24.365]		[33.098]		[14.868]
1^{st}trim.		-31.973		-16.415		-31.047		-4.773		55.749		-34.478
		[30.944]		[20.766]		[20.539]		[23.893]		[34.496]		[20.375]*
Number of obs.	17,300	17,300	78,789	78,789	50,632	50,632	45,457	45,457	17,009	17,009	79,080	79,080

Notes. All regressions include municipality, year and month of conception fixed effects, and control variables (the same variables as in Table 1). Standard errors clustered at the municipal level. ***p<0.01, **p<0.05, *p<0.1.

Robustness checks. We perform several robustness and sensitivity tests to confirm our main findings that birth weight responds to exposure during the third trimester of pregnancy. First, we show in Figure A.2 Panel (a) that our estimates are robust to different definitions of the control group. We vary the number of municipalities included in the simulated control group (first four estimates, all statistically significant at least at the 10% level), include municipalities located in the metropolitan region of the state capital, use all municipalities in the Doce River basin, and use all municipalities affected by the Brumadinho disaster and find similar results. Second, we exclude each treated municipality at a time to check whether the results are driven by a particular area and find remarkably stable estimates (Panel (b)).

4 Conclusion

In this paper we analyze the health effects of one of the largest environmental disasters of the world mining industry, which largely stemmed from regulatory failure. We show that *in utero* exposure to the disaster significantly reduced birth weight and increased infant mortality. The adverse effects were stronger for infants born to less educated and single mothers.

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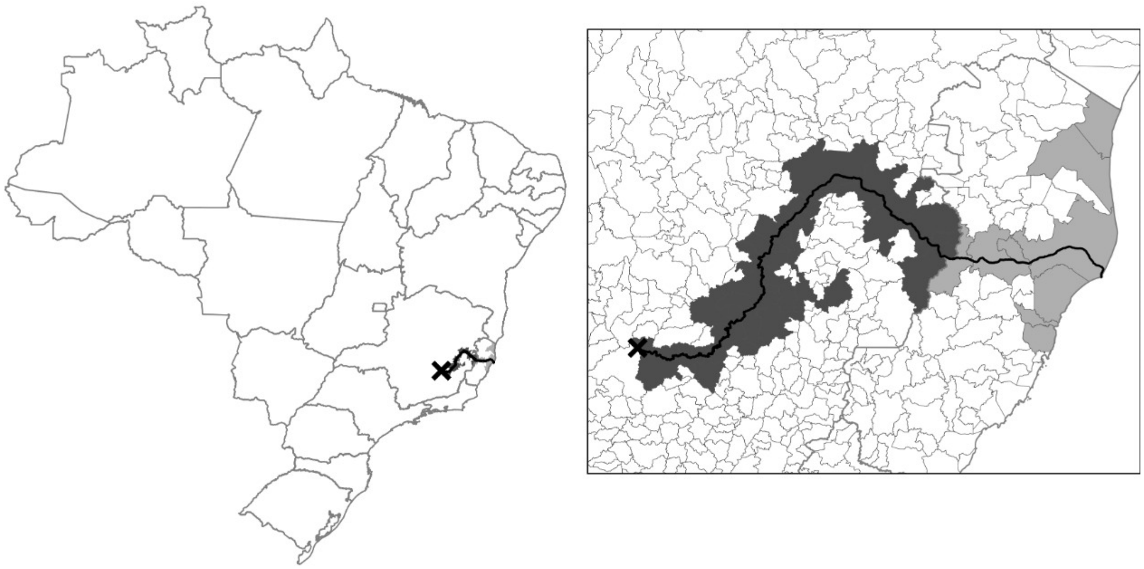
Appendix A

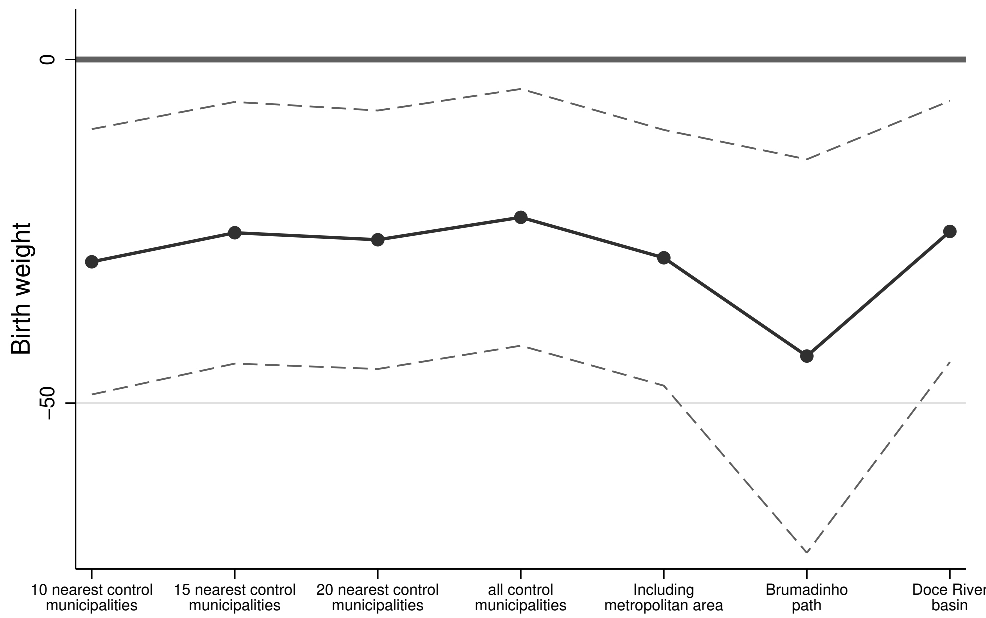
Figure A.1: Mariana dam collapse



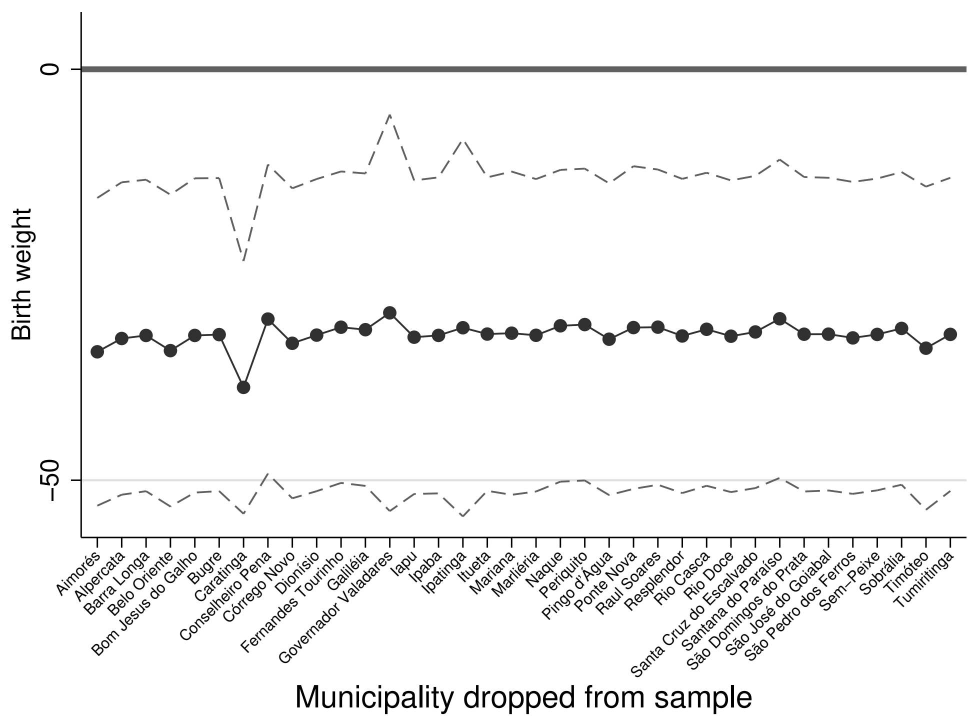
Notes. All municipalities affected by the Mariana dam disaster are in gray. Municipalities in our treated group – that are located in Minas Gerais state – are displayed in darker gray, while other municipalities affected by the disaster are in light gray.

Figure A.2: Robustness checks

(a) Other control groups



(b) Dropping each treated municipality



Notes. In Figure A.2a, we use the following definitions of the control group: pregnant women living in the 10, 15 and 20 most affected municipalities in the simulated path; including pregnant women living in municipalities located in the Belo Horizonte metropolitan region; including those living in all municipalities in the Doce River basin; and including the ones living in the municipalities affected by the Brumadinho disaster. Figure A.2b plots the estimated effect from Equation (2) from separate regressions in which each municipality affected by the disaster is excluded. Dashed lines show 95 percent confidence intervals.