# Environmental disasters and birth outcomes: impact of a tailings dam breakage in Brazil

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**Abstract**

There is evidence of a relationship between in utero exposure to catastrophic events and adverse birth outcomes, usually attributed to heightened maternal stress. The objective of our work was to evaluate if the breakage of a dam containing waste from a mining cite in Brazil, in 2015, an event popularly known as the Mariana Tragedy, affected the health of newborns exposed in utero. We used administrative data on birth records and reports on the Mariana Tragedy to identify all births from newborns exposed in utero and the intensity of that exposure, according to the mother's municipality of residence. Using a difference-in-differences framework, we estimated the impact of different intensities of exposure on birth outcomes. We found that being directly exposed in utero to the Tragedy resulted in 1.86 days shorter gestational age and 2.6 percentage points higher incidence of preterm birth (< 37 weeks). We found no impact on birthweight related outcomes. The effect is larger than previously identified for other catastrophic events. We hypothesize that this is probably due to the Tragedy impacting birth outcomes not exclusively through heightened maternal stress, but also through depressed economic activity in directly affected municipalities.

**Keywords:** birth outcomes; environmental disaster; maternal stress.
**JEL codes:** I10, J13, Q59.
**ANPEC Area:** Area 12 - Social Economics and Economic Demography.

**Resumo**

Existem evidencias sobre a relação entre a exposição a diversos tipos de desastres durante a gestação e a saúde ao nascer, geralmente atribuídos a um aumento do estresse materno. O objetivo do nosso trabalho é avaliar se a Tragédia de Mariana, a quebra de uma barragem contendo rejeitos de mineração no Brasil em 2015, afetou a saúde dos recém-nascidos expostos durante a gestação. Usamos dados administrativos sobre nascimentos (SINASC-DATASUS) para identificar todos os recém-nascidos expostos no útero à Tragédia e a intensidade dessa exposição, de acordo com o município de residência da mãe. Utilizando a técnica de diferença em diferenças, estimamos o impacto de diferentes intensidades de exposição sobre a saúde ao nascer. De acordo com os nossos resultados, a exposição em cidades diretamente afetadas levou a gestações 1.86 dias mais curtas e um aumento de 2.6 pontos percentuais na incidência de nascimentos prematuros (< 37 semanas). Não achamos nenhum impacto sobre o peso ao nascer e a incidência do baixo peso (< 2500 gramas). O efeito achado é maior do que o identificado para outros eventos catastróficos já estudados. Uma hipótese é que a Tragedia de Mariana tenha impactado a saúde dos recém-nascidos não só por um aumento do estresse materno, mas também por uma diminuição da atividade econômica nos municípios diretamente afetados.

**Palavras chave:** saúde ao nascer; desastre ambiental; estresse materno.
**Códigos JEL:** I10, J13, Q59.
**Área ANPEC:** Área 12 - Economia Social e Demografia Econômica.

# 1 Introduction

## 1.1 Catastrophic events, stress and neonatal health

The relevance of the prenatal environment for fetal development and its long-lasting consequences has attracted attention not only from the biomedical sciences, but also from economics and public health (Almond and Currie 2011; Almond, Currie, and Duque 2018; Gluckman et al. 2008). In relation to this, an important line of research is the relationship between maternal exposure to stress during pregnancy and neonatal health. Bussières et al. (2015) identify different forms used in the literature to measure and conceptualize maternal stress, among them the exposure to natural disasters or other catastrophic events.

The main hypothesized mechanism to explain the relationship between prenatal maternal stress and health at birth is the hypothalamic–pituitary–adrenal axis (HPA axis). When a pregnant woman is exposed to stress, the HPA axis is activated and heightens the levels of cortisol, which in turn leads to higher levels of placental corticotrophin-releasing hormone (CRH). Increased levels of CRH are associated with decreased fetal growth and pre-term delivery (Beijers, Buitelaar, and Weerth 2014; Wadhwa et al. 2004). Even though this mechanism is widely accepted as relevant, it is possible that heightened maternal stress during pregnancy affects birth outcomes also through other mechanisms, like a depressed immune system, which increases the risk of inflammatory reactions that might lead to pre-term birth (Beijers, Buitelaar, and Weerth 2014; Dunkel Schetter 2011). Also, higher stress levels might lead to prejudicial habits or health behaviors, like smoking or drinking alcohol, which could also be prejudicial for the newborn (Beijers, Buitelaar, and Weerth 2014; Dunkel Schetter 2011; Dunkel-Schetter and Lobel 2012).

Maternal exposure to stress during pregnancy may also have long-lasting effects. Some studies have found evidence that health at birth –measured by birthweight or gestational age- is positively correlated with cognitive development, educational outcomes and income in adult life (Black, Devereux, and Salvanes 2007; Figlio et al. 2014; Moster, Lie, and Markestad 2008). There is also evidence of longer lasting effects of stress during pregnancy on children health and educational attainment, independently of any manifestation at birth (Aizer, Stroud, and Buka 2016; King et al. 2012).

A frequently studied source of maternal stress is exposure to natural disasters or other kinds of catastrophic events. Following the definition of the United Nation Agency for Disaster Risk Reduction (UNISDR), a disaster can be defined as: "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts"[1]. Defining "crisis" in a similar fashion, Vogl and Bharadwaj (2015) highlight three relevant criterions for an event to be defined as such: it must be acute –meaning not long-lasting-, severe –meaning a large shock that profoundly affects an area- and unexpected –difficult to anticipate by individuals-.

A limitation of studies on the impact of in utero exposure to catastrophic events on neonatal health is that it is frequently not possible to directly measure maternal stress levels. In those cases, it is difficult to discard other possible causal channels through which disasters could affect health at birth. Specifically, if a large disaster disrupts economic activity, it might generate income reduction or job loss, which in turn could affect birth outcomes. In the literature about the impact of economic downturns on birth outcomes (Bozzoli and Quintana-Domeque 2014; Margerison-Zilko, Li, and Luo 2017; Olafsson 2016; Wehby, Gimenez, and López-Camelo 2017) two mechanisms are discussed. On the one hand, financial insecurity might increase maternal stress, which can lead to the same effects described above. On the other hand, there might be an income effect that leads to the reduction in the consumption of health-enhancing products,

[1]See in https://www.unisdr.org/we/inform/terminology (last accessed 18-11-2018).

mainly a nutritionally healthy diet.

In utero exposure to disasters and related stress have been measured in different forms. Some studies have directly measured stress levels of pregnant women exposed to disasters, either by measuring their levels of cortisol or by applying standardized questionnaires. Other studies have solely considered exposure to a natural disaster or other kind of catastrophic event as given by the pregnant women place of residence (Harville, Xiong, and Buekens 2010). The first kind of studies (King et al. 2012; Tan et al. 2009; Xiong et al. 2008) can directly assess stress levels and therefore discard other potential mechanisms through which in utero exposure to disasters could be harmful for neonatal health. However, the second kind of studies (Bozzoli and Quintana-Domeque 2014; Camacho 2008; Currie and Rossin-Slater 2013; Eskenazi et al. 2007; Kim, Carruthers, and Harris 2017; Quintana-Domeque and Ródenas-Serrano 2017; Tong, Zotti, and Hsia 2011; Torche 2011; Torche and Shwed 2015) usually work with administrative data on whole populations, which gives them an advantage in terms of the unbiasedness and size of the samples they work with. That allows them to make stronger causal claims about the effects of exposure to disasters on neonatal health but makes it difficult to disentangle the precise transmission mechanisms.

The kind of disasters considered in the reviewed studies can be grouped in two different kinds: natural disasters and acute armed violence. Quintana-Domeque and Ródenas-Serrano (2017) analyzed the impact of exposure during pregnancy to a terrorist attack in the mother's province of residence in Spain between 1980 and 2003. Using a database of birth registries in Israel between 2003 and 2009 that includes individual identifiers for the mother, Torche and Shwed (2015) exploited the outburst of the 2006 Second Lebanon War as a natural experiment to assess the effect of prenatal exposure to stress in Israel. Eskenazi et al. (2007) analyzed birth outcomes in New York City and upstate New York before and after the terrorist attack of 11 September 2001[2]. All three studies used administrative data on birth records and their results pointed similar directions. Both Quintana-Domeque and Ródenas-Serrano (2017) and Torche and Shwed (2015) found that exposure to armed violence was related with lower birthweight and a higher prevalence of low birth weight when it occurred during the first trimester of pregnancy. Torche and Shwed (ibid.) additionally report a negative effect on the duration of pregnancy when exposure happened in any of the first two trimesters. Eskenazi et al. (2007) found that exposure to the stress associated with the events of September 11, 2001, in New York, were associated with increases in low-birth weight when exposure was during the first or second trimester of pregnancy.

Studies on the effects of fetal exposure to natural disasters have focused either in earthquakes (Kim, Carruthers, and Harris 2017; Tan et al. 2009; Torche 2011) or different kind of storms: hurricanes (Currie and Rossin-Slater 2013), floods (Tong, Zotti, and Hsia 2011), and ice storms (King et al. 2012). The most relevant to us are the ones that make use of large datasets of administrative data on birth records, like our database. Currie and Rossin-Slater (2013) analyzed the impact of in utero exposure to hurricanes in Texas, USA, between 1996 and 2008, using a mother-fixed-effect model. They found no robust evidence of an impact on birthweight or gestational age but did find robust effects of disaster exposure during the third trimester on the probability of being born with an abnormal condition that originates in the perinatal period (e.g. meconium aspiration syndrome or assisted ventilation).

Torche (2011) evaluates the effects of the 2005 earthquake in Tarapaca, Chile, as a source of maternal stress on birth outcomes and finds a significant effect on birthweight, gestational age (both negative) and the probability of being born premature (positive), when exposed in utero during the first trimester in the region where the earthquake was more intense. Kim, Carruthers,

[2]The authors exclude all records from births close to the place where the World Trade Center was to exclude cases in which there was exposure to the toxic dust cloud. Currie and Schwandt (2016) analyze fetal exposure to the dust and link their results to the existing literature on the effects of air pollution on neonatal health.

and Harris (2017) did a similar exercise with the 1994 Northridge earthquake in Los Angeles, California, in the USA and found a positive, albeit little, effect on the probability of being born with low birthweight. These last two works rely on the unexpected and acute character of the earthquakes to exploit them as natural experiments, using a difference-in-differences methodology.

The objective of our work is to evaluate if the breakage of a dam containing waste from a mining cite in Brazil, in 2015, affected the health of newborns exposed in utero. This event had similar characteristics to other disasters: it was a large shock with a considerable impact on a circumscribable geographical area and was mostly unexpected to residents. However, an interesting difference is that while earthquakes and hurricanes are natural disasters, the *Mariana Tragedy* was an environmental disaster whose occurrence was responsibility of human actions, and, thus, potentially preventable. The occurrence of a similar disaster involving a tailing dam in the same region in January 2019 highlights the relevance of assessing every possible impact of those events.

Even though there is consensus about the prejudicial effects of exposure to catastrophic events during pregnancy, there is still debate on the most vulnerable periods of the gestational process and the specific birth outcomes affected. Also, considering that the event occurred in a middle-income country, with high poverty rates and low access to care in some regions, the effect of disasters is expectedly higher, because measures aimed at buffering the consequences of exposure are presumably weaker.

## 1.2 The *Mariana Tragedy*

On November 5, 2015, a dam containing mining waste from the *Samarco* mining company in Bento Rodrigues, a district of the Mariana municipality in Minas Gerais, a southeastern Brazilian state, had a breakage. Consequently, a mudflow containing mining waste advanced on parts of four different municipalities, all in Minas Gerais: Mariana, Barra Longa, Rio Doce, and Santa Cruz do Escalvado. The mudflow reached also the *Rio Doce* river and spread through its waters for approximately 600 kilometers, affecting 34 other municipalities (31 in Minas Gerais and 3 in Espírito Santo, a neighboring state). Due to the magnitude of the event and the extent of the damages, it remained popularly known as the *Mariana Tragedy.*

The report made by the task force organized by the government of Minas Gerais to assess the consequences of the dam breakage divides its effects according to two different regions: the four municipalities directly hit by the mudflow and the remaining municipalities, mainly affected by the pollution of the *Rio Doce* watercourse (Grupo da Força Tarefa 2016).

In the four municipalities directly affected, the mudflow caused 19 deaths and 256 injured people. In addition, over 600 people lost their house and 280 suffered related illnesses. Considering also other consequences (e.g. interruption of electricity and water supply, of health care and educational services, and destruction of physical infrastructure), 10,482 residents of those four municipalities were considered to have been directly impacted (ibid.).

In the municipalities affected by the pollution of the Rio Doce, the immediate consequences were linked to restrictions in the availability and quality of water. In 14 municipalities water supply was suspended due to the presence of toxic waste or turbidity above tolerable levels. This did not only temporally impact water for human consumption but also agriculture, fishing, tourism, and celluloid production, i.e., economic activities relevant for the region (Fernandes et al. 2016; Grupo da Força Tarefa 2016).

# 2 Methods

## 2.1 Data

In order to assess the effect of in utero exposure on birth outcomes , we used the microdata from the SINASC-DATASUS, the System of Information on Life Births from the Department of Informatics of the Unified Health System, i.e., the Brazilian National Health Service. As registration is compulsory and there is near total compliance, the system includes the universe of births in Brazil. Each observation corresponds to one live birth and provides information on the pregnancy, newborn, and mother characteristics. Additionally, we used data from the SIM-DATASUS, the System of Information on Mortality, that includes data from all death records, including fetal deaths, to estimate fetal mortality rates[3].

We first selected all births between 2013 and 2016 in the two states affected by the *Mariana Tragedy*: Minas Gerais and Espírito Santo. Further, we dropped all multiple births (2.4% of total observations), because the interpretation of indicators of neonatal health is different for those cases, and births that occurred outside hospitals (0.5%), in which recorded information is presumably less accurate (n = 1,231,567 births).

To avoid any potential selection problems that could arise from reproductive decisions being affected by exposure to the *Mariana Tragedy*, we limited our sample to births that occurred until July 2016, i.e. the ninth month since the dam breakage. We further dropped all births prior to August 2013 to have 3 full years of data (n = 914,795).

We then collapsed all birth data by municipality of residence of the mother and month and year of birth and constructed a panel with birth data from all municipalities from the states of Minas Gerais and Espírito Santo. We also estimated the count of fetal deaths by municipality of residence of the pregnant women and added that data to our panel. Our final database consists of a panel of 36 birth cohorts (from August 2013 to July 2016) in 931 municipalities and includes data from live births and fetal deaths.

We used data from reports on the consequences of the *Tragedy* (Grupo da Força Tarefa, 2016) that identify all 38 municipalities directly or indirectly affected: 35 in Minas Gerais -four directly and 31 indirectly- and three in Espírito Santo –all indirectly. We added binary variables indicating if the municipality of residence of the mother was directly or indirectly affected. As the *Tragedy* might have had an economic impact in some neighboring municipalities (Cavalcante Simonato et al, 2018), we added a third binary variable for municipalities that pertain to the same microregion[4] as a directly or indirectly affected one and might have been potentially affected. Figure 1 shows the location of affected municipalities, differentiating by the intensity of exposure to the *Tragedy*.

### 2.1.1 Dependent variables

We used data on the following birth outcomes: mean birthweight (in grams), mean gestational age (in weeks), proportion of low birthweight births (LBW, under 2500 grams), and proportion of preterm births (PTB, less than 37 weeks of gestation). As it is possible that injuries in utero result in miscarriages, we used two different measures to check for this: proportion of male births[5] and fetal deaths rate (fetal deaths per 1000 potential births, i.e. live births plus fetal deaths). We also checked if exposure to the *Mariana Tragedy* affected the number of births, as

[3]All data from SINASC/DATASUS and SIM/DATASUS is open access and is available in: http://datasus.saude.gov.br/informacoes-de-saude/servicos2/transferencia-de-arquivos (last accessed: 13/08/2018).

[4]The micro-regions were geographical areas defined by the Brazilian Institute of Geography and Statistics until 2017 for the elaboration of statistical information.

[5]There is evidence of a link between stress inducing events and a decline in the proportion of male births, due to selective fetal loss (Catalano and Bruckner 2006; Catalano, Bruckner, et al. 2006).

a way of measuring attrition due to migration.

### 2.1.2 Explanatory variables

We identified all births in affected and neighboring municipalities between November 2015 (the month of the dam breakage) and July 2016 (the ninth month). We considered three different levels of in utero exposure intensity. We adopted the classification of official reports and considered birth in those months in municipalities reached by the mudflow as directly affected and in municipalities near the *Rio Doce* as indirectly affected. We also considered births in those months in proximate municipalities (defined as those in the same microrregion as a directly or indirectly affected one) as potentially affected because we cannot discard that psychological or material effects of the *Tragedy* were not felt in neighboring cities. We therefore had three binary variables indicating if the newborn was potentially, indirectly or directly in utero affected by the consequences of the dam breakage. Additionally, we differentiated the timing of the exposure to identify if the specific gestational trimester of exposure was relevant.

### 2.1.3 Covariates

In the base specification of our difference-in-differences model, we included fixed effects for municipality of residence, for each month-and-year of birth -i.e., for the 36 birth cohorts-, for calendar month of birth, and a municipality-specific linear trend. In additional specifications, we added state-specific year fixed effects and/or maternal characteristics (i.e., percentage of mothers under 20 years old, percentage of black and brown mothers, percentage of single mothers and percentage of mothers with up to 7 years of education).

## 2.2 Estimation Strategy

To estimate the impact of the *Mariana Tragedy* on health at birth, we used a difference-in-differences framework. We estimated regressions of the following form (model 1):

$$\begin{aligned} y_{cmt} = \alpha &+ \beta_1\, directly\_affected_{cmt} + \beta_2\, indirectly\_affected_{cmt} \\ &+ \beta_3\, potentially\_affected_{cmt} + \gamma_c + \lambda_{mt} + \eta_m + \varphi\, Trend_{cmt} + \varepsilon_{cmt} \end{aligned} \tag{1}$$

Where $y_{cmt}$ is one of the dependent variables described above in municipality $c$, in month $m$, and year $t$. $directly\_affected_{cmt}$ indicates cohorts of newborns in municipalities reached by the mudflow between November 2015 and July 2016. $indirectly\_affected_{cmt}$ indicates cohorts of newborns in municipalities next to the *Rio Doce* between November 2015 and July 2016. $potentially\_affected_{cmt}$ indicates cohorts of newborns in that period in municipalities proximate to directly or indirectly affected ones. $\gamma_c$ is a municipality fixed effect, $\lambda_{mt}$ is a cohort (i.e, month-and-year of birth) fixed effect, $\eta_m$ is a calendar-month fixed effect to control for seasonality and $Trend_{cmt}$ is a municipality-specific time trend to allow for possible differences in pre-exposure trends. In additional specifications, we added state-specific year fixed effects. For regressions with birth outcomes as dependent variables, we also added maternal characteristics as covariates.

We also assessed the impact of the different levels of exposure to the *Mariana Tragedy* on birth outcomes according to the gestational trimester of exposure, estimating regressions of the following form, where $G$ represents the gestational trimester of exposure (model 2):

$$\begin{aligned} y_{cmt} = \alpha + \sum_{G=1}^{3} \beta_1 \, directly\_affected_{cmt} + \sum_{G=1}^{3} \beta_2 \, indirectly\_affected_{cmt} \\ + \sum_{G=1}^{3} \beta_3 \, potentially\_affected_{cmt} + \gamma_c + \lambda_{mt} + \eta_m + \varphi \, Trend_{cmt} + \varepsilon_{cmt} \end{aligned} \quad (2)$$

In all cases, robust standard errors were clustered at the municipality level to account for serial correlation and all regressions were estimated by least squares, weighted by the municipality average monthly number of births during the whole period.

# 3 Results

Table 1 shows summary statistics from all birth records grouped by the intensity of exposure to the *Tragedy* for the whole period (August 2013 - July 2016). The directly affected region is comparatively small, and comprises only one municipality with sizable population, Mariana, which had 58,802 inhabitants in 2015, i.e. 81% of the directly affected population. The indirectly affected region is considerably bigger and includes two cities with over 250,000 inhabitants in 2015: Ipatinga and Governador Valadares.

Considering the whole period, the incidence of LBW and PTB is lower in the indirectly and directly affected regions when compared to unaffected and potentially affected ones. Mean birthweight and gestational age are also higher. Maternal characteristics also differ among unaffected and affected regions. In unaffected municipalities there are proportionally less mothers with less than 8 years of schooling, but more single mothers, than in indirectly or directly affected municipalities. In directly affected municipalities, the proportion of teenage mothers is smaller and in indirectly affected municipalities the fraction of black and brown mothers is smaller than in all other regions.

Table 2 shows the results of estimating model 1 for four different birth outcomes: birthweight (in grams), gestational age (in weeks), and proportion of the newborns with LBW and PTB. For each dependent variable, the first column shows the results for our base model, the second column for the model adding maternal characteristics and the third column for the model adding also state-specific year fixed effects.

The results show that in utero exposure to the *Mariana Tragedy* in directly affected municipalities resulted in shorter pregnancies and a higher incidence of preterm births. Considering our base model, being directly exposed in utero to the *Tragedy* resulted in 1.86 days shorter mean gestational age and, more importantly, 2.6 percentage points higher incidence of preterm birth . Those results are robust to the inclusion of maternal characteristics and state-specific year fixed effects as additional controls in our regression, and in all cases significant at the 1% level. In utero exposure in those municipalities did not have a significant impact neither on mean birthweight nor on the incidence of LBW, although it is worth noting that the sign of the coefficient for LBW is opposite to the expected one for directly and indirectly affected cohorts.

A potential problem when estimating the impact of in utero exposure to some phenomena on birth outcomes is attrition in the affected cohorts. There is evidence that stressful conditions during pregnancy lead to fetal loss, and that they disproportionately affect male fetus. If that were the case in our study, we would have attenuation bias, because there would be missing newborns whose birth outcomes would be presumably worse. To check for this, we used two different measures: fetal deaths rate (number of fetal deaths per 1000 potential births) and the proportion of male births. An additional source of attrition could be maternal migration. If pregnant women residing in affected municipalities moved to other cities as a response to the *Tragedy* and after delivery the new city was recorded in birth certificates as the city of residence, we would expect the number of births in affected municipalities to decrease -and the number of births could in turn also be affected by fetal losses.

To check for the existence of those different forms of attrition, we estimated model 1 with number of births, fetal deaths rate and proportion of male births as dependent variables. Table 3 shows the results of our estimations. In all cases, we estimated both our base model and a model including state-specific year fixed effects. According to our results, there is evidence that in utero exposure to the *Tragedy* in indirectly affected municipalities -i.e., municipalities that are next to the *Rio Doce* but were not reached by the mudflow- led to miscarriages. In those municipalities, the *Tragedy* resulted in an increase of 4.2 fetal deaths per month per 1000 potential births (live births plus fetal deaths). However, as we did not find any effect on the number of births or the proportion of male births, these results should be taken with caution because fetal deaths are likely underreported and reporting rates might not be uniform among municipalities. In potentially and directly affected municipalities, we found no impact of the *Mariana Tragedy* on the number of births, fetal deaths rate or the proportion of male newborns. We interpret these results as a sign of absence of in utero selection and attrition due to maternal migration.

We further analyzed the relevance of the timing of in utero exposure to the *Mariana Tragedy*. We focused exclusively on gestational age and the incidence of PTB, the two outcomes for which we found an impact considering the whole gestation. The results are shown in table 4. We estimated the same three models as in table 2: our base model and models including state-specific year fixed effects and maternal characteristics. We found that in utero exposure during all gestational trimesters in directly affected municipalities significantly altered gestational age and the incidence of PTB, and the impact was larger when exposure was during the first trimester. Focusing on PTB as outcome and our base model (column 4), we found an impact of 3.6 p.p. on the incidence of PTB among the cohorts exposed during the first trimester. During the second and third trimester the impact was 2.1 and 2.5 percentage points, respectively.

Finally, we realized a series of robustness checks. We focused on PTB because it is the most interesting outcome, as it is the one associated with medical complications early in life and educational outcomes and income in adult life (Behrman and Butler 2007; Moster, Lie, and Markestad 2008). The results are shown in table 5. Columns 1 to 3 shows the results of running the same regressions as in columns 10 to 12 of table 2 but restricting the sample to municipalities in the state of Minas Gerais (where all directly affected municipalities are). This implied changing the composition of the control group by dropping all observations from the state of Espírito Santo. The coefficients for the impact of in utero exposure to the *Mariana Tragedy* on the incidence of PTB remain basically unchanged when compared to the ones in table 2. Columns 4 and 5 show the results of regressions ran directly from the microdata, without constructing the panel of municipalities, both including and not including maternal characteristics as covariates. The coefficients are somewhat smaller than in table 2 but point in the same direction and remain significant at the 1% threshold.

Additionally, as is common practice when applying the difference in differences methodology, we realized placebo tests. We first dropped all observations posterior to July 2015 and estimated the impact as if the *Mariana Tragedy* had occurred in November 2014 (column 6 of table 5). We did not find any impact of this mock *Tragedy.* Our second placebo, depicted in column 7, was a lead -i.e. we tested if there was an impact in the 9 months before it actually happened. Again, the coefficient for the fake exposure was non-significant, which adds credibility to our results.

Finally, Column 8 shows the results of adopting as interest variable the interaction between the binary variables indicating the level of in utero exposure and the proximity to the geographical location of the broken dam, measured by the inverse of the distance in kilometers from the geographical center of the city. The impact among newborns exposed in directly affected municipalities is similar to the one without considering the distance. For the municipality of Mariana, with a center located 19.72 kilometers of the dam and where most directly exposed cases are, the 0.525 coefficient implies a 2.7 p.p. increase in the percentage of children born premature, similar to the effect we had previously found. Taken together, all these robustness checks increase our confidence in the estimated impact of the *Mariana Tragedy* on prematurity.

# 4 Discussion

We found a significant and large impact of in utero exposure to the *Mariana Tragedy* in directly affected municipalities on mean gestational age at birth and the proportion of preterm newborns. Considering our base model, exposure in those municipalities resulted in gestations around 1.9 days shorter (0.266 weeks) and a 2.64 percentage points higher proportion of premature newborns. The impact was larger among those exposed in the first three months of gestation (2.79 days shorter gestation and a 3.64 p.p. increase in the proportion of premature babies) than in the second (1.99 days and 2.11 p.p.) or in the third (1.25 days and 2.51 p.p.). These results were robust to the inclusion of different covariates, to the restriction of our sample to births only in the most affected state, and to the use of microdata instead of a panel of data aggregated at the municipality level.

Even though we cannot completely discard migration of pregnant women as a result of exposure to the *Tragedy*, which seems likely in directly affected municipalities, we found no effect on the number of births, which gives us confidence in our results not being completely driven by endogenous migration. Additionally, we found no evidence of in utero selection due to fetal deaths in directly affected municipalities. We found an increase of fetal deaths in indirectly affected ones. Even though this result should be interpreted with caution due to problems with reporting of fetal deaths, it could mean that we underestimated the effect in those municipalities if more fragile fetus died in utero.

The results found are in line with previous studies indicating negative impacts of unexpected natural disasters on neonatal health. In our case, we only found those effects for weeks of gestation and preterm delivery, and notably larger in magnitude. Of the two studies most similar to ours, Torche (2011) and Kim, Carruthers, and Harris (2017), only the first one found an effect of in utero exposure to a disaster on gestational age and prematurity. In cities were the intensity of the analyzed earthquake was high, Torche (2011) found a 0.188 weeks reduction in gestational age and a 2.6 percentage points increased probability of being born premature among newborns affected in utero during the first trimester. She found no impact among those exposed in later trimesters. Additionally, in the context of exposure to acute armed violence, Torche and Shwed (2015) found a reduction of 0.099 weeks of gestation when exposed during the first trimester and of 0.095 when exposed during the second trimester of gestation.

The main limitation of our study, shared by many analyses on the impact of large-scale catastrophic events on neonatal health, is that we cannot directly test for the main hypothesized causal mechanism -i.e., that exposure heightens maternal stress levels, which in turn affects birth outcomes. We showed the existence of an association between in utero exposure to the *Mariana Tragedy* in highly affected municipalities and worse neonatal health, i.e. a higher proportion of premature births. However, it is not possible to state that the causal channel goes exclusively through heightened maternal stress.

In fact, it is possible that the higher effect found, when compared to exposure to other natural and non-natural disasters, is due to the presence of more than one channel linking exposure to the *Tragedy* and birth outcomes. According to the official report of the government of Minas Gerais (the state in which all four directly affected municipalities are located), the event did not only cause direct human harm, but had also a significant impact on infrastructure and disrupted economic activity. A study based on simulations using a computable general equilibrium model (Cavalcante Simonato, Domingues, and Souza Magalhães 2018) estimated a decrease in private consumption between 1.22% and 1.74% due to the *Tragedy* in Mariana, the most affected municipality and where 87.4% of newborns directly affected were born. Even though that is an estimation based on a simulation, and we cannot extrapolate it directly to pregnant women, the magnitude of the impact of the event in directly affected municipalities makes it unlikely that the effect on birth outcomes goes exclusively through heightened maternal stress level due to exposure to the dam breakage. Disruption of local economic activity can be an additional source of maternal stress, but it might also have a negative impact on personal income and reduce the consumption of health-enhancing products. It is therefore likely that our estimates reflect both stress-related and not stress-related channels through which exposure led to worsened birth outcomes.

Despite the difficulties in identifying the causal channel, the magnitude of the association between exposure to the *Mariana Tragedy* and preterm birth highlights the necessity of designing and implementing interventions focused on pregnant women during natural or environmental disasters. Preterm infants are more likely to develop complications early in life (e.g., respiratory conditions, a compromised immune system, cardiovascular disorders), which leads to an increase in the need of medical care services and higher neonatal (under 28 days) and infant (under 1 year) mortality rates (Behrman and Butler 2007; Moster, Lie, and Markestad 2008). Additionally, preterm birth has been associated with lower wages and educational levels in adult life (Moster, Lie, and Markestad 2008).

# 5 Conclusion

We showed that the breakage of a tailings dam in Southeastern Brazil was related with shorter pregnancies and an increase in the proportion of preterm births ($< 37$ weeks of gestational age) for newborns exposed in utero in municipalities directly affected -i.e, reached by the mudflow. Our results are robust to different model specifications and in line with previous findings about the impacts of catastrophic events on neonatal health but considerably larger, possibly due to the combination of stress-related and not stress-related channels through which exposure led to worsened birth outcomes.

# References


Aizer, Anna, Laura Stroud, and Stephen Buka (2016). "Maternal Stress and Child Outcomes: Evidence from Siblings". In: *Journal of Human Resources* 51.3, pp. 523–555. ISSN: 0022-166X, 1548-8004. DOI: 10.3368/jhr.51.3.0914-6664R.

Almond, Douglas and Janet Currie (2011). "Human Capital Development before Age Five". In: *Handbook of Labor Economics*. Vol. 4 b. Amsterdam: Elsevier, pp. 1315–1485.

Almond, Douglas, Janet Currie, and Valentina Duque (2018). "Childhood Circumstances and Adult Outcomes: Act II". In: *Journal of Economic Literature* 56.4, pp. 1360–1446. ISSN: 0022-0515. DOI: 10.1257/jel.20171164.

Behrman, Richard E. and Adrienne Stith Butler (2007). *Preterm Birth: Causes, Consequences, and Prevention.* Washington D.C.: National Academies Press, Committee on Understanding Premature Birth and Assuring Healthy Outcomes.

Beijers, Roseriet, Jan K. Buitelaar, and Carolina de Weerth (2014). "Mechanisms underlying the effects of prenatal psychosocial stress on child outcomes: beyond the HPA axis". In: *European Child & Adolescent Psychiatry* 23.10, pp. 943–956. ISSN: 1018-8827, 1435-165X. DOI: 10.1007/s00787-014-0566-3.

Black, S. E., P. J. Devereux, and K. G. Salvanes (2007). "From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes". In: *The Quarterly Journal of Economics* 122.1, pp. 409–439. ISSN: 0033-5533, 1531-4650. DOI: 10.1162/qjec.122.1.409.

Bozzoli, Carlos and Climent Quintana-Domeque (2014). "The Weight of the Crisis: Evidence From Newborns in Argentina". In: *Review of Economics and Statistics* 96.3, pp. 550–562. ISSN: 0034-6535, 1530-9142. DOI: 10.1162/REST_a_00398.

Bussières, Eve-Line et al. (2015). "Maternal prenatal stress and infant birth weight and gestational age: A meta-analysis of prospective studies". In: *Developmental Review* 36, pp. 179–199. ISSN: 02732297. DOI: 10.1016/j.dr.2015.04.001.

Camacho, Adriana (2008). "Stress and Birth Weight: Evidence from Terrorist Attacks". In: *American Economic Review* 98.2, pp. 511–515. ISSN: 0002-8282. DOI: 10.1257/aer.98.2.511.

Catalano, R. and T. Bruckner (2006). "Secondary sex ratios and male lifespan: Damaged or culled cohorts". In: *Proceedings of the National Academy of Sciences* 103.5, pp. 1639–1643. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.0510567103.

Catalano, R., T. Bruckner, et al. (2006). "Exogenous shocks to the human sex ratio: the case of September 11, 2001 in New York City". In: *Human Reproduction* 21.12, pp. 3127–3131. ISSN: 1460-2350, 0268-1161. DOI: 10.1093/humrep/del283.

Cavalcante Simonato, Thiago, Edson Paulo Domingues, and Aline Souza Magalhães (2018). "Projeção dos impactos econômicos regionais do desastre de Mariana-MG". In: *Textos para Discussão Cedeplar-UFMG* 586.

Currie, Janet and Maya Rossin-Slater (2013). "Weathering the storm: Hurricanes and birth outcomes". In: *Journal of Health Economics* 32.3, pp. 487–503. ISSN: 01676296. DOI: 10.1016/j.jhealeco.2013.01.004.

Dunkel Schetter, Christine (2011). "Psychological Science on Pregnancy: Stress Processes, Biopsychosocial Models, and Emerging Research Issues". In: *Annual Review of Psychology* 62.1, pp. 531–558. ISSN: 0066-4308, 1545-2085. DOI: 10.1146/annurev.psych.031809.130727.

Dunkel-Schetter, Christine and Marci Lobel (2012). "Pregnancy and Birth Outcomes: A Multilevel Analysis of Prenatal Maternal Stress and Birth Weight". In: *Handbook of Health Psychology: Second Edition*. Ed. by Andrew Baum. 2nd ed. Psychology Press. ISBN: 978-0-203-80410-0. DOI: 10.4324/9780203804100.

Eskenazi, Brenda et al. (2007). "Low birthweight in New York city and upstate New York following the events of September 11th". In: *Human Reproduction* 22.11, pp. 3013–3020. ISSN: 1460-2350, 0268-1161. DOI: 10.1093/humrep/dem301.

Fernandes, Geraldo Wilson et al. (2016). "Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana, Brazil". In: *Natureza & Conservação* 14.2, pp. 35–45. ISSN: 16790073. DOI: 10.1016/j.ncon.2016.10.003.

Figlio, David et al. (2014). "The Effects of Poor Neonatal Health on Children's Cognitive Development". In: *American Economic Review* 104.12, pp. 3921–3955. ISSN: 0002-8282. DOI: 10.1257/aer.104.12.3921.

Gluckman, Peter D. et al. (2008). "Effect of In Utero and Early-Life Conditions on Adult Health and Disease". In: *New England Journal of Medicine* 359.1, pp. 61–73. ISSN: 0028-4793, 1533-4406. DOI: 10.1056/NEJMra0708473.

Grupo da Força Tarefa (2016). *Avaliação dos efeitos e desdobramentos do rompimento da Barragem de Fundão em Mariana-MG*. Belo Horizonte: Secretaria de Desenvolvi-

mento Regional, Política Urbana e Gestão Metropolitana, Governo do Estado de Minas Gerais.
Harville, Emily, Xu Xiong, and Pierre Buekens (2010). "Disasters and Perinatal Health: A Systematic Review." In: *Obstetrical & Gynecological Survey* 65.11, pp. 713–728. ISSN: 0029-7828. DOI: 10.1097/OGX.0b013e31820eddbe.
Kim, Bongkyun, Celeste K. Carruthers, and Matthew C. Harris (2017). "Maternal stress and birth outcomes: Evidence from the 1994 Northridge earthquake". In: *Journal of Economic Behavior & Organization* 140, pp. 354–373. ISSN: 01672681. DOI: 10.1016/j.jebo.2017.05.014.
King, Suzanne et al. (2012). "Using Natural Disasters to Study the Effects of Prenatal Maternal Stress on Child Health and Development: Natural Disasters and Prenatal Maternal Stress". In: *Birth Defects Research Part C: Embryo Today: Reviews* 96.4, pp. 273–288. ISSN: 1542975X. DOI: 10.1002/bdrc.21026.
Margerison-Zilko, Claire E, Yu Li, and Zhehui Luo (2017). "Economic Conditions During Pregnancy and Adverse Birth Outcomes Among Singleton Live Births in the United States, 1990–2013". In: *American Journal of Epidemiology* 186.10, pp. 1131–1139. ISSN: 0002-9262, 1476-6256. DOI: 10.1093/aje/kwx179.
Moster, Dag, Rolv Terje Lie, and Trond Markestad (2008). "Long-Term Medical and Social Consequences of Preterm Birth". In: *New England Journal of Medicine* 359.3, pp. 262–273. ISSN: 0028-4793, 1533-4406. DOI: 10.1056/NEJMoa0706475.
Olafsson, Arna (2016). "Household Financial Distress and Initial Endowments: Evidence from the 2008 Financial Crisis: HOUSEHOLD FINANCIAL DISTRESS AND INITIAL ENDOWMENTS". In: *Health Economics* 25, pp. 43–56. ISSN: 10579230. DOI: 10.1002/hec.3426.
Quintana-Domeque, Climent and Pedro Ródenas-Serrano (2017). "The hidden costs of terrorism: The effects on health at birth". In: *Journal of Health Economics* 56, pp. 47–60. ISSN: 01676296. DOI: 10.1016/j.jhealeco.2017.08.006.
Tan, Cong E. et al. (2009). "The Impact of the Wenchuan Earthquake on Birth Outcomes". In: *PLoS ONE* 4.12. Ed. by Qamaruddin Nizami, e8200. ISSN: 1932-6203. DOI: 10.1371/journal.pone.0008200.
Tong, Van T., Marianne E. Zotti, and Jason Hsia (2011). "Impact of the Red River Catastrophic Flood on Women Giving Birth in North Dakota, 1994–2000". In: *Maternal and Child Health Journal* 15.3, pp. 281–288. ISSN: 1092-7875, 1573-6628. DOI: 10.1007/s10995-010-0576-9.
Torche, Florencia (2011). "The Effect of Maternal Stress on Birth Outcomes: Exploiting a Natural Experiment". In: *Demography* 48.4, pp. 1473–1491. ISSN: 0070-3370, 1533-7790. DOI: 10.1007/s13524-011-0054-z.
Torche, Florencia and Uri Shwed (2015). "The Hidden Costs of War: Exposure to Armed Conflict and Birth Outcomes". In: *Sociological Science* 2, pp. 558–581. ISSN: 23306696. DOI: 10.15195/v2.a27.
Vogl, Tom and Prashant Bharadwaj (2015). "Crisis and Human Biology". In: *The Oxford Handbook of Economics and Human Biology*. Ed. by John Komlos and Inas R. Kelly. Vol. 1. Oxford University Press. ISBN: 978-0-19-938929-2. DOI: 10.1093/oxfordhb/9780199389292.001.0001.
Wadhwa, Pathik D. et al. (2004). "Placental corticotropin-releasing hormone (CRH), spontaneous preterm birth, and fetal growth restriction: A prospective investigation". In: *American Journal of Obstetrics and Gynecology* 191.4, pp. 1063–1069. ISSN: 00029378. DOI: 10.1016/j.ajog.2004.06.070.

Wehby, George L., Lucas G. Gimenez, and Jorge S. López-Camelo (2017). "The impact of unemployment cycles on child and maternal health in Argentina". In: *International Journal of Public Health* 62.2, pp. 197–207. ISSN: 1661-8556, 1661-8564. DOI: 10.1007/s00038-016-0857-1.

Xiong, Xu et al. (2008). "Exposure to Hurricane Katrina, Post-traumatic Stress Disorder and Birth Outcomes". In: *The American Journal of the Medical Sciences* 336.2, pp. 111–115. ISSN: 00029629. DOI: 10.1097/MAJ.0b013e318180f21c.

# Tables and figures

Table 1: Summary statistics

| | Unaffected | Potentially affected | Indirectly affected | Directly affected |
|---|---|---|---|---|
| Number of municipalities | 806 | 87 | 34 | 4 |
| Number of births | 811,526 | 48,608 | 51,883 | 2,778 |
| Population (in 2015) | 22,024,656 | 1,354,009 | 1,348,143 | 72,204 |
| Monthly fetal deaths rate | 11.4 | 11.9 | 10.0 | 11.0 |
| | | | | |
| Mean birthweight | 3170 | 3174 | 3216 | 3173 |
| Mean gestational age | 38.55 | 38.56 | 38.63 | 38.65 |
| LBW | 0.078 | 0.076 | 0.068 | 0.073 |
| PTB | 0.100 | 0.103 | 0.094 | 0.096 |
| Male | 0.512 | 0.513 | 0.514 | 0.525 |
| | | | | |
| Maternal characteristics | | | | |
| Age $<$ 20 years old | 0.159 | 0.162 | 0.158 | 0.148 |
| Black or brown | 0.618 | 0.621 | 0.557 | 0.610 |
| $<$ 8 years of formal education | 0.198 | 0.242 | 0.208 | 0.209 |
| Single | 0.399 | 0.336 | 0.272 | 0.367 |

*Note:* The table shows the data for the whole period (August 2013 - July 2016) aggregated by the intensity of exposure to the *Mariana Tragedy* of the municipality of residence of the mother.

Table 2: Estimation of Model 1: intensity of in utero exposure and birth outcomes

| | Birthweight | | | Gestational age | | | LBW | | | PTB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| potentially_affected | -7.1769 | -7.1880 | -8.2135 | 0.0131 | 0.0118 | 0.0129 | 0.0015 | 0.0016 | 0.0018 | 0.0075 | 0.0075 | 0.0080 |
| | (10.3879) | (10.3991) | (10.5419) | (0.0448) | (0.0445) | (0.0445) | (0.0053) | (0.0053) | (0.0053) | (0.0060) | (0.0060) | (0.0061) |
| indirectly_affected | -0.4951 | -0.5203 | -0.8187 | -0.0458 | -0.0487 | -0.0488 | -0.0051 | -0.0049 | -0.0049 | 0.0031 | 0.0031 | 0.0031 |
| | (0.9532) | (0.9509) | (0.9237) | (0.1572) | (0.1512) | (0.1467) | (0.3134) | (0.3500) | (0.3438) | (0.6132) | (0.6067) | (0.6058) |
| directly_affected | -10.1943 | -10.1478 | -9.9593 | -0.2662*** | -0.2605*** | -0.2584*** | -0.0163 | -0.0166 | -0.0170 | 0.0264*** | 0.0263*** | 0.0258*** |
| | (18.7705) | (18.7775) | (19.1464) | (0.0425) | (0.0426) | (0.0426) | (0.0119) | (0.0119) | (0.0122) | (0.0037) | (0.0037) | (0.0037) |
| Maternal characteristics | No | No | Yes | No | No | Yes | No | No | Yes | No | No | Yes |
| Month fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| State-specific year fixed effect | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |
| Observations | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 |
| R-squared | 0.2039 | 0.2039 | 0.2061 | 0.2724 | 0.2731 | 0.2733 | 0.0865 | 0.0866 | 0.0878 | 0.1315 | 0.1317 | 0.1337 |

*Note:* robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Birthweight is measured in grams and gestational age in weeks. LBW: low birthweight ($< 2500$ grams). PTB: preterm birth ($< 37$ weeks of gestation). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. * p-value $< 0.1$, ** p-value $< 0.05$, *** p-value $< 0.01$.

Table 3: Estimation of Model 1: intensity of in utero exposure and attrition

| | Number of births | | Fetal deaths rate | | Sex = male | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| potentially_affected | 13.9020 | 13.6473 | 1.3343 | 1.3446 | 0.0049 | 0.0050 |
| | (8.9998) | (8.6501) | (1.7842) | (1.7753) | (0.0103) | (0.0103) |
| indirectly_affected | 3.7166 | 3.1224 | 4.1553*** | 4.1787*** | -0.0013 | -0.0010 |
| | (9.7865) | (9.1942) | (1.3076) | (1.3094) | (0.0114) | (0.0112) |
| directly_affected | 10.9999 | 12.1338 | -3.9028 | -3.9468 | 0.0064 | 0.0058 |
| | (8.9415) | (9.7738) | (3.6665) | (3.6749) | (0.0087) | (0.0087) |
| Month fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| State-specific year fixed effect | No | Yes | No | Yes | No | Yes |
| Observations | 33,516 | 33,516 | 32,594 | 32,594 | 32,565 | 32,565 |
| R-squared | 0.9971 | 0.9971 | 0.0940 | 0.0941 | 0.0584 | 0.0586 |

*Note:* robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Birthrate: number of births per 1000 inhabitants. Fetal deaths rate: number of fetal deaths per 1000 potential births (births + fetal deaths). Sex = male: proportion of male newborns. * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Table 4: Estimation of Model 2: timing and intensity of exposure and gestational age

| | Gestational age | | | PTB | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| potentially_affected_1trim | -0.0229 | -0.0244 | -0.0225 | 0.0081 | 0.0081 | 0.0086 |
| | (0.0679) | (0.0671) | (0.0664) | (0.0092) | (0.0092) | (0.0092) |
| indirectly_affected_1trim | -0.0468 | -0.0504 | -0.0505 | 0.0042 | 0.0042 | 0.0040 |
| | (0.0461) | (0.0448) | (0.0445) | (0.0057) | (0.0057) | (0.0058) |
| directly_affected_1trim | -0.3975*** | -0.3904*** | -0.3868*** | 0.0364*** | 0.0363*** | 0.0362*** |
| | (0.0646) | (0.0647) | (0.0655) | (0.0072) | (0.0073) | (0.0070) |
| potentially_affected_2trim | -0.0178 | -0.0204 | -0.0194 | 0.0127* | 0.0128* | 0.0135** |
| | (0.0519) | (0.0520) | (0.0519) | (0.0066) | (0.0066) | (0.0067) |
| indirectly_affected_2trim | -0.0625* | -0.0687** | -0.0690** | 0.0038 | 0.0040 | 0.0041 |
| | (0.0365) | (0.0326) | (0.0324) | (0.0064) | (0.0066) | (0.0065) |
| directly_affected_2trim | -0.2848*** | -0.2731*** | -0.2716*** | 0.0211*** | 0.0207*** | 0.0202*** |
| | (0.0387) | (0.0388) | (0.0389) | (0.0067) | (0.0068) | (0.0068) |
| potentially_affected_3trim | 0.0572 | 0.0572 | 0.0578 | 0.0032 | 0.0031 | 0.0034 |
| | (0.0495) | (0.0495) | (0.0498) | (0.0068) | (0.0068) | (0.0068) |
| indirectly_affected_3trim | -0.0323 | -0.0323 | -0.0322 | 0.0019 | 0.0018 | 0.0019 |
| | (0.0585) | (0.0583) | (0.0582) | (0.0081) | (0.0080) | (0.0080) |
| directly_affected_3trim | -0.1787*** | -0.1785*** | -0.1767*** | 0.0251*** | 0.0252*** | 0.0245*** |
| | (0.0517) | (0.0518) | (0.0510) | (0.0051) | (0.0051) | (0.0054) |
| Maternal characteristics | No | No | Yes | No | No | Yes |
| Month fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| State-specific year fixed effect | No | Yes | Yes | No | Yes | Yes |
| Observations | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 | 32,566 |
| R-squared | 0.2725 | 0.2732 | 0.2734 | 0.1315 | 0.1317 | 0.1338 |

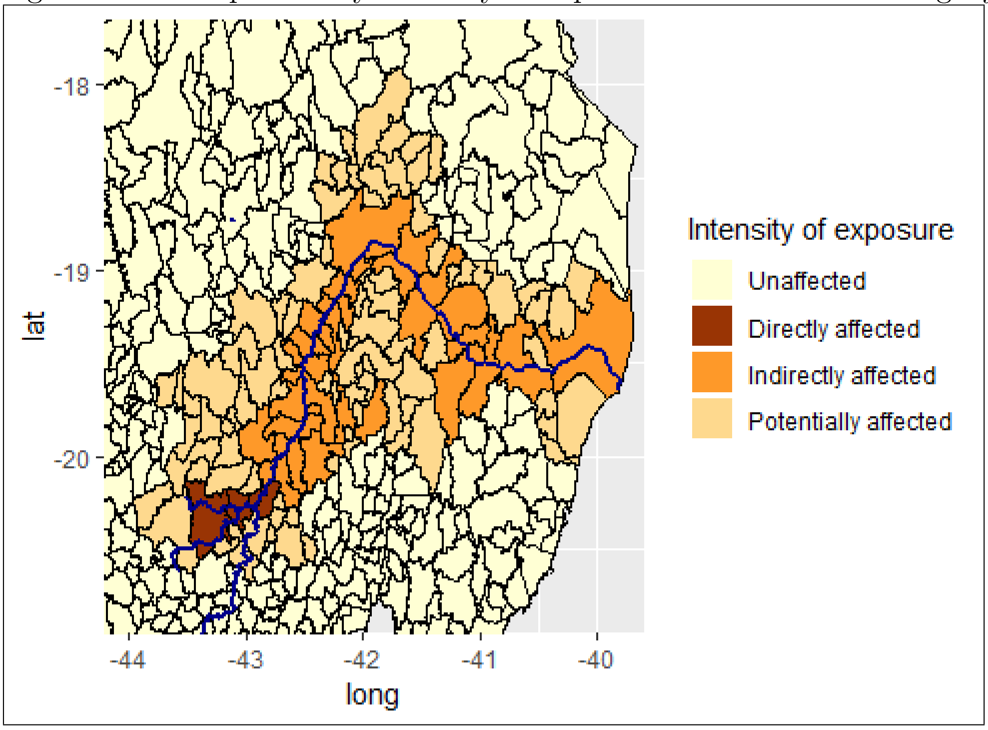
*Note:* robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Gestational age is measured in weeks. PTB: preterm birth ($<$ 37 weeks of gestation). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. * p-value $< 0.1$, ** p-value $< 0.05$, *** p-value $< 0.01$.

Table 5: Impact of in utero exposure to the Mariana Tragedy on PTB: robustness checks

| | PTB | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| potentially_affected | 0.0053 | 0.0055 | 0.0055 | 0.0056 | 0.0061 | | 0.0073 | 0.1230 |
| | (0.0073) | (0.0074) | (0.0074) | (0.0046) | (0.0046) | | (0.0132) | (0.2277) |
| indirectly_affected | -0.0041 | -0.0039 | -0.0039 | 0.0031 | 0.0030 | | 0.0043 | -0.4549 |
| | (0.0054) | (0.0057) | (0.0057) | (0.0059) | (0.0060) | | (0.0102) | (0.7512) |
| directly_affected | 0.0264*** | 0.0258*** | 0.0258*** | 0.0225*** | 0.0227*** | | 0.0366*** | 0.5253*** |
| | (0.0037) | (0.0037) | (0.0037) | (0.0046) | (0.0044) | | (0.0102) | (0.0380) |
| potentially_affected_placebo | | | | | | 0.0027 | -0.0002 | |
| | | | | | | (0.0087) | (0.0080) | |
| indirectly_affected_placebo | | | | | | 0.0056 | 0.0010 | |
| | | | | | | (0.0072) | (0.0057) | |
| directly_affected_placebo | | | | | | -0.0028 | 0.0085 | |
| | | | | | | (0.0084) | (0.0104) | |
| Maternal characteristics | No | Yes | Yes | No | Yes | No | No | No |
| Month fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| State-specific year fixed effect | No | No | Yes | No | No | No | No | No |
| Interacted with inverse of distance | No | No | No | No | No | No | No | Yes |
| Observations | 29,762 | 29,762 | 29,762 | 914,795 | 914,795 | 21,686 | 32,566 | 32,566 |
| R-squared | 0.1214 | 0.1233 | 0.1233 | 0.0060 | 0.0085 | 0.1563 | 0.1315 | 0.1314 |

*Note:* robust standard errors clustered at the municipality level between parentheses. Columns 1 to 3 include only municipalities in the state of Minas Gerais. Columns 4 and 5 include results from microdata (each birth is one observation) instead of the panel of municipalities. In column 6 the interest variable is a placebo Tragedy in November 2014. In column 7, we have both our original interest variables and a lead (a placebo Tragedy 9 months before the real one). In column 8, our interest variable are the original ones interacted with the inverse of the distance between the geographical center of the municipality and the broken mining dam. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. PTB: preterm birth ($< 37$ weeks of gestation). When considered in panel models, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. When considered in models with microdata are binary variables indicating the age (younger than 20, 20 to 24, 25 to 34, 35 or older), education (less than 8 years, 8 to 11 years, 12 years or more, ignored), race (black, brown, white, indigenous, Asian, ignored), and marital status (single, married, divorced, widow, consensual union, ignored).* p-value $< 0.1$, ** p-value $< 0.05$, *** p-value $< 0.01$.

Figure 1: Municipalities by intensity of exposure to the Mariana Tragedy




*Source:* author's elaboration with data from the Brazilian Institute of Geography and Statistics (IBGE).
*Note:* the map does not include all unaffected municipalities.