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Water Scarcity and Birth Outcomes in the Brazilian Semiarid

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Abstract

This paper analyzes the impact of rainfall fluctuations during the gestational period on health at birth. We concentrate on the semiarid region of Northeastern Brazil to highlight the role of water scarcity as a determinant of early life health. We find that negative rainfall shocks are robustly correlated with higher infant mortality, lower birth weight, and shorter gestation periods. Mortality effects are concentrated on intestinal infections and malnutrition, and seem to be greatly minimized when the local public infrastructure is sufficiently developed (municipality coverage of piped water and sewerage). We also find that effects are stronger during the fetal period (2^{nd} trimester of gestation) and for children born during the dry season. The results seem to be associated with the effects of water scarcity per se, and not reduced agricultural production, on birth outcomes.

JEL Codes: I15, I25, Q54
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1 Introduction

An estimated 900 million people in the world today live with inadequate access to water supplies and 2.7 billion live without improved sanitation facilities (World Health Organization (2010)). For this population, collecting water for consumption, hygiene, and agricultural production is a daily task that demands energy and resources. In addition, lack of adequate access to water increases the susceptibility to climatic shocks associated with variations in rainfall. Notoriously, water scarcity in these contexts can reduce agricultural production and nutrient intake, impacting health outcomes. It can also directly lead to increased incidence of infectious diseases, such as diarrhoea and acute respiratory infections, particularly affecting young children and pregnant women (World Health Organization (2010) and (2012)).

This paper analyzes the impact of rainfall fluctuations during the gestational period on health at birth. We concentrate on the semiarid region of Northeastern Brazil – the driest region in the country – to highlight the role of water scarcity as a determinant of early life health. This region has long been subject to harsh climatic conditions, with intermittent events of drought, water scarcity and food insecurity (see, for example, SUDENE (1981), Ab'Sáber (1999), and Áridas (1995)). We examine whether and how idiosyncratic shocks to rainfall during the time in utero affect a range of health outcomes at birth, including birth weight, number of weeks of gestation, and infant mortality (by cause of death, gender, season of birth, and time since birth). We also explore the specific channels linking variation in rainfall to health outcomes at birth. In our setting, there are two main potential connections in this relationship: water scarcity may be associated with lower agricultural production and, therefore, lower nutrient intake; and water scarcity may lead to lack of safe drinkable water and higher incidence of infectious diseases.

This research has considerable data requirements. We make use of high frequency gridded information on precipitation and temperature to construct a municipality-by-month weather dataset. This dataset is then combined with birth and mortality registration records to create a municipality-by-month panel on weather conditions and birth outcomes. Our identification strategy relies on the hypothesis that temporary rainfall deviations from historical averages, conditional on municipality-by-month fixed-effects, are uncorrelated with other latent determinants of health during gestation. Under this assumption, we are able to identify the causal impact of rainfall variations on birth outcomes.

Our results indicate that negative rainfall shocks are robustly correlated with higher infant mortality, lower birth weight, and shorter gestation periods. Mortality effects are concentrated on intestinal infections and malnutrition, and seem to be greatly minimized when the local public health infrastructure is sufficiently developed. The estimated effects of rainfall fluctuations decrease monotonically with municipality coverage of piped water and sewerage, loosing statistical significance when coverage of these public goods is sufficiently high. At the same time, results do not seem to be associated with agricultural production, remaining virtually unchanged when we control for production per capita in the years surrounding birth. We also find that effects are stronger during the fetal period (2^{nd} trimester of gestation) and for children born during the dry season. Overall, our results indicate that we are capturing the effects of scarcity of drinkable water per se, and not reduced agricultural production, on birth outcomes.

A series of recent papers have addressed the relationship between environmental shocks and health and socioeconomic outcomes. Deschenes and Moretti (2009), for example, analyze the impact of temperature fluctuations on mortality in the US, while Burgess et al. (2011) conduct a similar exercise for India. Deschenes et al. (2009) show, also for the US, that exposure to high temperatures during pregnancy leads to lower birth weight. In relation to rainfall in particular, there has been a growing body of research exploring different settings and potential channels. Maccini and Yang (2009) look at rural Indonesia and find long lasting impacts (health, education and labor market outcomes) of early-life rainfall fluctuations for women, with no noticeable effects for men. Positive deviations during the first year of life are associated with better outcomes during adulthood, while no significant effect is found for rainfall fluctuations before birth. Kudamatsu et al. (2010) use DHS data for various African countries to analyze the impact of rainfall fluctuations on infant mortality by malaria and malnutrition. They find that increased rainfall is associated with higher mortality by malaria in epidemic, but not in endemic areas, supposedly due to higher acquired immunity in the latter. When looking at malnutrition, they find no significant impact on the average, but highly non-monotonic heterogeneous effects. Their results suggest that, in arid areas, both increased rainfall and droughts are associated with higher infant mortality. Using as well DHS data for West Africa, Kim (2010) also finds no association on average between rainfall fluctuation before birth and in the first year of life and infant mortality, but uncover a similarly puzzling positive relationship during the growing season. Kim (2010) rationalizes this results by suggesting that positive rainfall shocks during the growing season increase the demand for labor in agriculture, reducing the time mothers spend with children and compromising breastfeeding. Skoufias et al. (2011) look at rural areas in Mexico and find that rainfall variations do not impact negatively household welfare as measured by consumption expenditure, but, similarly to the papers mentioned before, that positive rainfall shocks have a negative impact on child health. The authors suggest that this result should be taken as evidence of a pathway through the disease environment. Aguilar and Vicarelli (2011), looking again at Mexico, find that children born around years and regions affected by floods caused by the El Niño phenomenon experience slower anthropometric growth and cognitive development. In their case, this effect seems to be driven by reduced household income as a results of the flood. Finally, Burgess et al. (2011), despite focusing on the impact of temperature variations, do present some borderline significant results on the positive impact of low incidence of rainfall on overall mortality, which seem to work through lower agricultural productivity and higher food prices.

Overall, the evidence on the effect of rainfall variations on health is largely mixed, with both positive and negative impacts estimated in different settings, as well as non-significant results. This should come as no surprise, since it is not clear a priori whether positive variations in rainfall should be seen as beneficial or harmful events. As recognized, among others, by Maccini and Yang (2009) and Kudamatsu et al. (2010), there are various potential channels linking variations in rainfall to health and socioeconomic outcomes. Within an usual range of variation, increases in rainfall may increase agricultural production and lower food prices, improving nutrition and health. But rainfall may also increase the incidence of infectious diseases for which the vector's reproduction cycle or the transmission mechanism trust on the availability of water, such as malaria, schistosomiasis, and dengue fever. Rainfall may also directly increase the availability of safe drinkable water, reducing the incidence of infectious diseases and improving the absorption of nutrients. Finally, either too much or too little water (floods or droughts) may disrupt agricultural production and impact rural households' income and access to food.

The simultaneous operation of all these channels is likely to be responsible for the heterogeneous results obtained across the studies mentioned above, and also to be behind some puzzling non-monotonic effects estimated in specific cases. Our focus on a semiarid region helps solve this problem and renders positive rainfall variations into unequivocally beneficial events. We obtain clear-cut and robust results on the effect of rainfall variations during pregnancy on an expanded set of birth outcomes. Our set of indicators include birth weight, length of gestation, and mortality by cause of death. Finally, we are able to go one step further and link the results specifically to the availability of safe drinkable water and, as opposed to the previous literature, to rule out the most commonly considered channel through agricultural production. Despite not being explicitly considered in previous studies, water scarcity is extremely relevant to rural populations in the developing world. Close to 1 billion people today, among the poorest in the planet, live in arid and semiarid areas and this number is expected to increase with climate change (World Bank (2008), United Nations Development Programme (2006)).

The public health literature has long understood the mechanisms linking water scarcity and health outcomes. There are even estimates available of the likely impact of access to water and sanitation on the incidence of diarrhoeal diseases and child mortality. But these are based on the distribution of diseases across the globe and on a theoretical relationship between water and sanitation access and health conditions. There is no direct evidence or causal estimate available on the observed health outcomes that can be unequivocally attributed to water scarcity or on the quantitative role of water and sanitation infrastructure in minimizing the effects of climatic shocks in a real setting. The optimal design of policies responsive to climate change and increasing weather fluctuations requires knowledge on how and to what extent observed natural phenomena impact human health and development.

These results are particularly relevant in light of the mounting evidence on the long-term effects of early life conditions on cognitive development and human capital accumulation (Shenkin et al. (2004), Linnet et al. (2006), Mara (2003),Almond and Currie (2010), Glewwe and Miguel (2008), Currie (2009)).

The remainder of the paper is organized as follows. Section 2 describes our empirical setting and provides a conceptual discussion of the links between water scarcity and health. Section 3 presents the data and descriptive statistics. Section 4 details our empirical strategy. Section 5 presents and analyzes the results. Finally, section 6 concludes the paper.

2 Background

2.1 The Brazilian Semiarid Northeast

The Brazilian Northeast comprises 9 states and 1,800 municipalities. Its semiarid region is located mostly inland and includes 1,048 municipalities. We follow the official definition of the semiarid region given by the Brazilian Ministry of National Integration (ordinance #89/2005). According to this definition, a municipality is part of the semiarid region if it satisfies one of three climatic characteristics (SUDENE (2008)): (i) it is within the boundaries of isohyets below 800mm , i.e., the lines on a map joining points of historical average precipitation below 800mm (yearly precipitation records from 1961 to 1990); (ii) it has average Thorntwaite Index below 0.50 (this indicator combines humidity and aridity indices to determine an area's moisture regime); and (iii) it has an index of risk of drought above

60% (the index is defined as the share of days under hydric deficit, which accounts for daily precipitation and evapotranspiration, also calculated with data from 1961 to 1990).

The semiarid Northeast is the poorest region in Brazil. Roughly 80% of children are below the poverty line and infant mortality reaches 31 per 1,000 births, as opposed to the Brazilian averages of, respectively, 25% and close to 15 per 1,000 births. Around 53% of its 20 million dwellers live in rural areas, compared to 19% for the country as a whole. Municipalities are typically small, with population median around 12 thousand inhabitants.[1] The semiarid economy is largely based on extensive forms of subsistence agriculture and cattle raising, with very low productivity and great dependence on weather fluctuations (Ab'Sáber (1999), Áridas (1995), SUDENE (1981), Áridas (1995), Cirilo (2008)).

The region is also the driest in Brazil. Figure 1 portrays the yearly precipitation between 1938 and 2008 for the semiarid region of the Northeast and for areas of Brazil outside the semiarid (the source of these data is discussed in the next section). Average historical precipitation in the semiarid is slightly below 750 mm, corresponding to less than half the average for the rest of the country (around 1700 mm). The figure also shows that events of rainfall scarcity have been recurrent throughout the past decades. This is consistent with existing historical evidence: various authors document severe droughts in the early 1950s, 1958, 1970, early 1980s, early 1990s, and 1998 (SUDENE (1981), Campos (1994), Villa (2000)). All these episodes can be seen in Figure 1.

The pattern of weather fluctuation within years is shown in Figure 2. There are two marked seasons: the rainy season (first semester), with precipitation levels particularly high between February and April, when sowing typically takes place; and the dry season (second semester), with monthly precipitation levels often close to zero. Temperatures, in contrast, vary little, with monthly averages always between 22° C and 26° C. Episodes of drought typically occur when precipitation during the first semester is unexpectedly low and irregular. Coupled with the geographic characteristics of the region, these episodes can seriously jeopardize water supplies.

The semiarid has a very poor network of rivers, with weak runoff volumes. This is due to the variability of rain over time and to the composition of the soil, which is mostly shallow and formed from crystalline rocks. This formation leads to little accumulation of water and low exchange between rivers and adjacent soil, resulting in a dense network of intermittent rivers. In addition, groundwater wells have typically low flow and provide water

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[1] Mortality data from Datasus and socioeconomic information from the 2000 Census. Child poverty rate is the share of individuals aged between 0 and 14 living in households with per capita income below the poverty line (defined as R$75.50, or 1/2 the August 2000 minimum wage).

of high salinity (Cirilo (2008)). Most of the water used in the region is obtained from dams and rainwater ponds, which vary in capacity from a couple of state sponsored reservoirs of billions of cubic meters (m^3), to several thousand smaller private reservoirs of up to 200,000 m^3 (Rebouças (1997)).

These dams and ponds accumulate water during the rainy season and are used throughout the year. But, in reality, there is severe underuse during the rainy season, due to lack of planning and fear of future water scarcity. As a result, there is substantial loss of water due to evaporation and, in the dry season, the remaining water displays high levels of salinity and low quality for consumption. Potential evaporation in the region reaches 2,500 mm per year (Cirilo (2008)), with the hydrologic efficiency of the water reserves estimated to be roughly 1/5 of their volume (Rebouças (1997)). As Rebouças (1997) notices, some ponds reach salinity levels higher than those registered in the Dead Sea. When rainfall during the rainy season is low, this problem is intensified and scarcity of high quality water becomes a major issue. To further enhance this scenario, local bodies of water are still the main destination of sewage, and the primitive forms of agriculture and cattle raising – also concentrated around water – further contribute to the depletion of the soil and to the reduction of the available reserves (Cirilo (2008)).

We believe that our focus on a semiarid region presents a series of advantages in relation to the previous literature on rainfall fluctuations, such as Maccini and Yang (2009) and Kudamatsu et al. (2010). First, the semiarid region turns positive rainfall shocks into unequivocally beneficial events, avoiding the non-monotonic effects that are present in Kudamatsu et al. (2010) and that are also a potential issue for the case of Indonesia analyzed by Maccini and Yang (2009).[2] This allows us to look at the effect of water scarcity, per se, on birth outcomes. Second, arid and semiarid regions cover one third of the earth's land surface. According to the World Bank's *World Development Report 2008*, one-third of the developing world's rural population, corresponding to 820 million people among the poorest in the planet, live in these areas (World Bank (2008)). With changing climate, arid and semiarid regions are expected to become even more prevalent (United Nations Development Programme (2006)). In the Brazilian Northeast itself, the El Niño phenomenon has increased the severity of droughts, and rising temperatures are expected to enhance evaporation and reduce water availability (Cirilo (2008)).

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[2] Figure 1 shows that yearly precipitation in the semiarid region of Northeastern Brazil did not reach the historical average for the rest of the country at any point in time. In the 70-year interval portrayed, this did not happen even in the extreme outlier for positive rainfall shocks, which was the year of 1986.

2.2 Water and Health

Water is life, but it is also a means of transmission of diseases and transportation of contaminants. Drinking water can deliver pathogens and toxic substances, hazards that are greatly enhanced in the absence of sanitation and waste management services. Inadequate water resources management can also affect water ecology leading to the proliferation of vectors of diseases, such as malaria, schistosomiasis, and dengue fever (Fewtrell et al. (2007)). Finally, either too much or too little water can disrupt agricultural production, reducing food availability and increasing malnutrition (United Nations Development Programme (2006)).

We focus here on water scarcity. In such context, two of the channels described above gain particular relevance. First, lack of water may directly impact households dependent on agriculture through reduced intake of nutrients, due to lower production and, consequently, poorer and less varied diets. This leads to malnutrition and micronutrient deficiency, potentially including deficits of vitamins A, B1, B3, and C, and iron (World Health Organization (2012)). Second, lack of adequate water supply combined with poor sanitation increases the risk of infectious diseases, most importantly diarrhoea, and respiratory infections. Indirectly, due to reduced capacity to absorb nutrients, diarrhoea also leads to increased malnutrition (World Health Organization (2012)).

The impact of water scarcity on health through reduced agricultural production is straightforward, but its impact through infectious diseases may seem less obvious. The key aspect in this connection is the fact that, in poor rural regions in developing countries, water quantity *means* water quality. Increases in water quantity increase the use of water for personal hygiene, reduce the travel time to collect water, reduce the need to store water in unsanitary conditions, and increase the quality of the traditional sources of water. In contexts of water scarcity, these tend to generate health benefits that far outweigh those that could be obtained from improvements in water quality, for a given quantity (Sobsey (2002), Mara (2003), Pond et al. (2011)).

In combination with poor sanitation, inadequate access to water is the leading risk factor for diarrhoeal diseases. Diarrhoea is caused mainly by pathogens that are ingested from unsafe water, contaminated food or hands. It is alone the second most important factor in the global burden of diseases (World Health Organization (2010)). For children, its estimated burden is greater than that of HIV, malaria, and tuberculosis combined, with a total of 1.8 million deaths each year. In addition, roughly 50% of childhood deaths attributed to malnutrition are thought to be associated with severe repeated diarrhoea (and other intestinal infections) and the resulting incapacity to absorb nutrients (United Nations Development

Programme (2006), World Health Organization (2010)). Malnutrition, in turn, also increases the susceptibility to and severity of new infections, reinforcing a vicious cycle (see discussion in Fewtrell et al. (2007)).

Together with young children and the elderly, pregnant women – and their fetuses – are particularly vulnerable to the health problems associated with water scarcity (Pond et al. (2011)). Biological demands for water and nutrients are greatly increased during pregnancy. With gestation, body water increases by 7 to 8 liters, which are roughly shared between the maternal and fetal placental compartments (Barron (1987)). Increased basal metabolism and tissue synthesis also increase the demand for nutrients. Requirements of proteins, fats, various vitamins (including A, B1, B3, and C), iron, iodine, and zinc are enhanced. Deficient intake of some of these may lead to birth defects, low birth weight, obstetric complications, premature birth, and higher perinatal mortality (Steegers-Theunissen (1995)). Water deprivation by itself may also lead to dehydration-anorexia, resulting in an additional channel of nutrient stress (Ross and Desai (2005)).

Generally, fetal growth, length of the gestation period, and birth weight are thought to be associated with offsprings' improved health outcomes. Fetal growth is mainly regulated by nutrition. Marginal changes in maternal nutrition do not necessarily lead to changes in fetal nutrition, as the fetus lies at the end of a long supply line (Bloomfield and Harding (1998)). But significant maternal malnutrition implies that the fetal substrate may not meet fetal demands, leading to a deceleration in the fetal growth trajectory (Bloomfield et al. (2006)). Low maternal body-mass index and intrauterine growth restrictions are considered risk factors for neonatal conditions. According to the medical literature, poor fetal growth is rarely a direct cause of death, but rather can contribute indirectly to neonatal deaths, particularly those due to birth asphyxia and infections (sepsis, pneumonia, and diarrhoea), which together are estimated to account for about 60% of neonatal deaths in the world (Black et al. (2008)).

The relevance of the issue is further amplified by the fact that fetal growth trajectory and birth weight may have long-term effects. The fetal origins hypothesis argues that in utero environmental influences can have permanent impacts through the underdevelopment of organs and predisposition to chronic diseases during adulthood (Barker (1998a), Barker (1998b), Ross and Desai (2005)). Fetal malnutrition in critical periods of rapid cell division is identified as a key factor in this relationship. Protein deficits, for example, have been associated with delayed brain development, as discussed in Morgane et al. (1993). In fact, while causal empirical evidence is limited, many studies in medical sciences and psychology suggest that low birth weight and other early life insults may lead to impaired cognitive development (Shenkin et al. (2004), Linnet et al. (2006), Mara (2003)). A large body of literature has also documented that schooling may be directly affected by early life health conditions, both in utero and during childhood (Almond and Currie (2010), Glewwe and Miguel (2008), Currie (2009)).

In this paper, we focus on the effects of rainfall fluctuations during the gestational period on health outcomes at birth. Since we concentrate our analysis on the Brazilian semiarid, we see variations in rainfall as shocks to water scarcity. In this context, increased rainfall is possibly related to increased agricultural production and availability of food and nutrients (Suliano et al. (2009), Maccini and Yang (2009)),[3] and also to increased access to safe drinkable water, which may reduce the incidence of infectious diseases (Parry et al. (2007), Luna (2007), Kudamatsu et al. (2010)).

3 Data and Descriptive Statistics

3.1 Climate Data

We construct historical series of precipitation and temperature using the *Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02* (Matsuura and Willmott (2009)). This dataset provides worldwide monthly temperature and precipitation estimates at the 0.5 × 0.5 degree level (0.5 degree corresponds roughly to 56 kilometers). Estimates for each node in this grid are obtained from calculations based on an average of 20 nearby weather stations. We first locate each municipality in our sample within a square defined by the four closest nodes. Henceforth, we call this square associated with a given municipality its *grid*. Following, we construct monthly precipitation and temperature series for each municipality as the weighted average of the estimates associated with the four nodes of its *grid*, where the weights are the linear distances from the municipality's centroid to each node.

We construct two variables measuring rainfall fluctuation during an individual's gestation period. The first variable is defined by the following equation

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[3] For instance, Suliano et al. (2009) estimated that a 1% increase in yearly precipitation levels is associated with a 0.4% rise in overall agricultural production in the Brazilian state of Ceará. See Maccini and Yang (2009) for a discussion on this issue for rural areas in Indonesia.

$$R_{m\tau} = \ln\left(\sum_{t=\tau-11}^{\tau} r_{mt}\right) - \ln\left(\overline{r}_m\right),$$

where r_{mt} indicates the monthly rainfall in municipality m and month t, $\overline{r}_m$ is the average historical yearly rainfall in municipality m, and τ indicates an individual's month of birth. Thus, $R_{m\tau}$ is defined as the deviation between the natural logarithm of the total rainfall in the 12 months prior to the individual's birth and the natural logarithm of the average yearly rainfall in municipality m. The historical average $\overline{r}_m$ is calculated for each municipality over the period from 1938 to 2008. The variable $R_{m\tau}$ can be approximately interpreted as the percentage deviation from mean rainfall. For instance, a value of 0.01 means that rainfall over the 12 months prior to an individual's birth was roughly 1% above normal. Maccini and Yang (2009) use a similar variable, but they construct rainfall fluctuations from data aggregated into seasons (6 month-periods), leading to measurement error in the rainfall attributed to pre and post-natal periods. The way our variable is constructed allows for a more precise measurement of the timing of rainfall. In order to conduct some robustness exercises and to control for other dimensions of climatic variations, we also construct variables measuring temperature (average in the 12 months prior to birth) and rainfall in other periods (12 to 24 months before birth and post-natal).

The second variable is a dummy designed to capture extreme events, similar to that used by Kudamatsu et al. (2010). We define an episode of drought in the following way

$$D_{m\tau} = 1 \text{ if } \sum_{t=-11}^{\tau} r_{mt} < \left(\overline{r}_m - r_m^{SD}\right), \text{ and 0 otherwise,}$$

where r_m^{SD} is the historical yearly standard deviation of rainfall for municipality m (calculated over the 1938-2008 period). In words, $D_{m\tau} = 1$ indicates that rainfall over the 12 months prior to an individual's birth was more than one standard deviation below the historical average for municipality m.

Figure 3 presents the yearly averages for the two variables defined above. The figure shows that the incidence of rainfall shocks in the semiarid varies significantly in the time-series and in the cross-section. Panel A portrays the rainfall log-deviation, which has a standard deviation of 0.31. Panel B presents the time series of the drought variable, which highlights how the severity of shocks varies geographically within a given month. Episodes of drought occur, on average, in 14% of the municipalities in the sample. Still, there are periods with pervasive droughts hitting almost 100% of the municipalities and periods with no municipality experiencing a drought.

3.2 Health Outcomes

We construct a dataset on health at birth and infant mortality combining microdata from the Brazilian National System of Information on Birth Records (Datasus/SINASC) and the National System of Mortality Records (Datasus/SIM). The first database records every registered birth in Brazil – around 13.7 million in the semiarid region alone from 1996 to 2008 – and provides information on, among other things, birth weight and length of gestation. The database also provides the exact date of birth, the municipality of birth, and the municipality of residence of the mother. This information allows us to construct a municipality-by-month of birth panel over the 1996-2008 period containing information on total number of births, average birth weight, and average length of the gestation period.

The National System of Mortality Records gathers information on every death officially recorded in Brazil. It contains data on cause of death, date of birth, municipality of birth, and municipality of residence. We select all deaths of individuals up to one year of age in the semiarid region of the Northeast between 1996 and 2008 (making a total of 378,000 infant deaths). We then build a municipality-by-month of birth panel for the 1996-2008 period containing information on the number of infant deaths (total and by cause of death).

These panels on births and infant mortality are merged by municipality and month of birth. The consolidated dataset allows us to calculate infant mortality rates by municipality and month of birth. Finally, we combine this dataset with our weather data by linking month and municipality of birth with municipality-specific measures of rainfall over the 12 months prior to the individuals' birth. Table 1 presents summary statistics for this dataset. Average number of births per month in a municipality is 28.9 (the median, not shown in the table, is only 14). Average birth weight is 3.3 kilograms and 94% of pregnancies last 37 weeks or more. The average number of infant deaths per month is 0.84, with infant mortality rates of 31.3 per 1,000 births. In this sample, the average incidence of rainfall in a typical 12-month period is 800 mm, with an average rainfall log-deviation of 0.022 and 9.7% of municipalities experiencing droughts.

4 Empirical Strategy

Our sample is composed of municipalities in the semiarid region of the Northeast of Brazil. The analysis of the health impacts of rainfall fluctuations during the gestation period is based on a municipality-by-month of birth panel. Our benchmark specification is the following

$$H_{myt} = \alpha + \beta R_{myt} + \phi_{mt} + \lambda_y + \varphi Trend_{gyt} + \pi T_{myt} + \epsilon_{myt},$$

where H_{myt} is a health outcome (municipality average) for children born in municipality m, on year y and month t; R_{myt} is our rainfall variable (either log-deviation of rainfall in the 12 months prior to birth or a dummy indicating a drought in the same period); ϕ_{mt} is a fixed-effect for municipality m and calendar month t (with $t = 1, 2, ..., 12$); λ_y is an year fixed-effect; T_{myt} is the average temperature in the municipality in the same 12-month period; $Trend_{gyt}$ is a grid-specific linear time trend; and ϵ_{myt} is a random error term. Our key dependent variable (H_{myt}) is infant mortality, but we also look at birth weight, length of gestation, infant mortality by cause of death, number of births, and sex-ratio at birth.

The main concern in this specification is the possibility of confounding omitted factors correlated both with rainfall and health at birth. This is clearly the case in the cross-section, since places with harsher climate tend to have worse socioeconomic conditions. But notice that we have 12 monthly fixed-effects in each of the 1,048 municipalities, resulting in over 12,500 additive independent variables. They control for any effect associated with climatic or socioeconomic conditions typical of specific months of the year in a given municipality. So recurrent level effects – possibly associated with wet and dry seasons, harvests, availability of food, etc – are all washed away in the municipality-by-month fixed-effects.

Year fixed-effects, in turn, capture aggregate shocks impacting the entire semiarid region. Grid-specific time trends control for potential long-run differences in climatic dynamics across regions, or for other socioeconomic changes that may be taking place within states. As mentioned before, we call grid the square defined by the four nodes closest to a municipality centroid (from the 0.5 × 0.5 degree weather dataset). This linear time trend is common to all municipalities included in a given grid. Finally, the control for temperature accounts for other climatic variations possibly correlated with rainfall also taking place at the municipality level.

Our identification relies on the assumption that a temporary rainfall deviation from its historical average – conditional on long-term trend and temperature variation – is uncorrelated with any latent determinant of health at birth. Under this assumption, we are able to identify the causal impact of rainfall variations on early life outcomes. It is difficult to think of plausible stories of endogeneity or omitted factors when considering this type of temporary variation in rainfall, conditional on all our independent variables. Still, there are multiple potential channels through which rainfall may affect health at birth. We also analyze the role of the main potential channels.

In all specifications, we use robust standard errors clustered by grid, the level at which we measure rainfall and temperature. Also, since mortality and other birth related variables are measured with less precision when there are fewer births, our benchmark specification weights observations by the average number of births per month. Lastly, since large urban centers may have different characteristics and may end up greatly influencing the results in a weighted regression setting, we trimmer from the sample municipalities in the top 1% of the distribution of number of births (above 289).

In trying to understand the results from our benchmark specification and to shed light on the channels linking variations in rainfall to birth outcomes, we look at the heterogeneity of effects across various margins. We analyze boys and girls separately; look at rainfall variation in different moments of the gestational period and at different seasons of the year; analyze impacts over various mortality horizons; and look at heterogeneous responses by municipality coverage of treated water, sanitation, and level of income per capita (calculated using 2000 Census files). In some robustness exercises, we also control for local agricultural production, in order to analyze whether rainfall impacts are working through food availability or water scarcity per se (from the Brazilian Census Bureau, IBGE).

A potential problem pervading our analysis concerns fetus selection due to adverse weather conditions. This type of caveat is recurrently mentioned in the birth weight literature (see, for example, Currie (2009), p.106). The problem is that only surviving fetuses are recorded in our dataset. Hence, shocks which tend to cull weak fetuses before birth or reduce women's fertility due to health or behavioral responses may lead the population of surviving newborns to be stronger than it would otherwise have been. As Currie (2009) argues, fetal selection suggests that estimated coefficients may understate the true negative effects of health insults.[4]

Figure 4 shows the pattern of monthly averages of number of births and infant mortality in our dataset, for periods with and without droughts (defined according to the variable discussed before). Not surprisingly, infant mortality tends to be higher for births in periods with droughts, and particularly so between July and December. Interestingly, the seasonal

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[4] This survivor-bias has long worried the empirical research on the health and welfare (Gorgens et al. (2011)). For example, Friedman (1982) suggests this type of bias as a possible explanation for the increased height of slaves in Trinidad. Bozzoli et al. (2009) find that population height increases with mortality rate for countries where infant mortality exceeds a threshold level. And Gorgens et al. (2011) use data from the 1959-1961 Great Chinese Famine and find that taller children were more likely to survive the famine. They also find no apparent pattern of stunting amongst famine cohorts. However, when controlling for selection, the authors estimate that children who survived the famine grew up to be shorter.

pattern of mortality is much more pronounced in periods with drought. Analogous but inverted patterns are observed for number of births. The number of births tends to be lower in periods with drought, and this difference is particularly large in the 2^{nd} half of the year. In our dataset, periods with higher mortality are periods with fewer births, so that the effect of drought on surviving children seems to be larger than the potential selection effect. Still, the same issue discussed by Currie (2009) is likely to be at work here, meaning that the true effects of rainfall on birth outcomes are likely to be stronger than those estimated here (on the assumption that part of the negative impacts are reflected on miscarriages). Selection effects through mother's fertility are also possible, given that unhealthy women are less likely to become pregnant.

Finally, in our setting, it is unlikely that we could have selection from conscious choices of parents, through delayed pregnancy in anticipation of negative rainfall shocks. Given that we explore transitory variations in rainfall, this would require an extremely sophisticated forecast of the likelihood of rainfall over several months following conception. This does not seem realistic. In any case, selection at birth is likely to bias estimated coefficients toward positive values, reducing the estimated impact of rainfall variation on birth outcomes.

5 Results

5.1 Benchmark Specification

Table 2 presents the results from our benchmark specification on the effect of rainfall fluctuations on infant mortality. We start in column 1 with the lightest specification and progressively introduce changes to the estimating equation, until we get to the full specification from our benchmark specification in column 4. The first column includes municipality-by-month fixed-effects, year of birth fixed-effects, and grid-specific linear time trends. The second column excludes municipalities in the top percentile of number of births (above 289), since these are likely to be larger urban centers where the mechanisms we explore should not be so relevant. In column 3, we weight observations by the average number of births, as the variance of mortality rates is larger for municipalities with fewer births. Following, in column 4, we control for the average temperature in the 12 months prior to birth, in order to make sure that the effect we are capturing is not due to broader climatic changes. Finally, in column 5, we conduct our first and probably most important robustness exercise, by analyzing whether rainfall variation during pregnancy is not in reality capturing the effect of rainfall in other periods (before conception and after birth). In order to tackle this issue, we control for rainfall deviations in the period comprising 12 to 24 months before birth and in the first year of life. Panel A presents this sequence of columns when we use the log of rainfall variation as our independent variable, and Panel B presents analogous results when we use our measure of drought.

Panel A shows that there is a negative and statistically significant correlation between rainfall and child mortality. Increases in rainfall during the gestation period are associated with reduced mortality during the first year of life. Results remain virtually unchanged when we move from column 1 to column 2, indicating that municipalities in the top 1% of the number of births are playing no role in generating the observed correlation. In column 3, when we weight regressions by the average number of births, the coefficient increases by more than 50% in magnitude, remaining strongly significant. This should be expected if the variance of mortality is higher for smaller municipalities (TRUE? Yes, it is). In column 4, when we control for temperature during pregnancy, results remain almost identical, indicating that the effects we are capturing seem to come particularly from rainfall, rather than from broader climatic conditions.

As mentioned before, column 5 in Table 2 already introduces our first robustness test. One main potential concern in this initial specification is that rainfall variation during pregnancy is correlated with rainfall variation in other periods – for example, before conception or after birth – and it is indeed rainfall in these other periods that affect health outcomes. Maternal nutrition before conception might determine the quality of fertilized eggs, having impacts on the formation of the fetus, while rainfall during the first year of life might directly affect children's nutrition and disease environment. Medical studies of the relationship between maternal health and birth weight suggest that the period before and around conception is important for the fetus growth trajectory. Birth weight of a newborn is reported to be correlated with the pre-pregnancy weight of the mother (as reviewed in Bloomfield et al. (2006)). Early postnatal conditions can also be critical once infant health is vulnerable to shortages of potable water and to the disease environment after birth. On the other hand, as argued by Kudamatsu et al. (2010), breast-feeding is known to lower mortality risk during that period. As long as it is not very severe, maternal malnutrition has little impact on the volume and composition of breast milk (Brown and Dewey (1992) apud. Kudamatsu et al. (2010), p.19). To address these concerns, the last column in Table 2 includes as additional controls the log deviation of rainfall in the 12 to 24 month interval before birth and in the first year of life. The added variables turn out to be both negative, but neither is statistically significant. The result is identical if we include each of these variables separately, one at time.

In addition, when they are included in the regression, the coefficient on rainfall during the gestation period increases in magnitude and remains statistically significant. It seems to be indeed the amount of rainfall during the gestation period that is affecting infant mortality, rather than rainfall at other moments in time.

In Panel B, we present analogous results using drought as the independent variables. The qualitative patterns are similar – indicating in this case that droughts are associated with increased infant mortality – though a little less precisely estimated in the first two columns. Overall, irrespective of how we measure rainfall variations, we detect a negative and statistically significant effect of increased water availability on infant mortality. Column 4 is our preferred specification and is the one we use in the remainder of the paper. The magnitude of the coefficient on the log of rainfall deviation is also quantitatively important. A 30% – or one standard deviation – increase in rainfall leads to a reduction of 2.14 in the infant mortality rate, or 7% of the mean. This result supports the view that variations in infant mortality in the semiarid region are strongly associated with rainfall fluctuations.

In Table 3, we further explore the health consequences of rainfall variation by looking at two additional birth outcomes – birth weight and length of gestation – and infant mortality by cause of death. We keep the specification from column 4 in Table 2 in all cases. Our variable measuring the length of gestation is the fraction of births in a municipality in a given month that reached at least 37 weeks. Regarding infant mortality by cause of death, we look at the main drivers of early mortality: intestinal infections, malnutrition, respiratory infections, perinatal period conditions, congenital diseases, and also non-reported causes. Finally, Table 3 also looks at number of births and sex ratio at birth, to shed further light on the potential selection that may be at work in this setting.

The first two columns show that increased water availability, in addition to reducing child mortality, increases birth weight and the probability of full-term pregnancies, though the effects are quantitatively small. A 30% increase in rainfall is associated with an increase of 1.9 grams in birth weight and of 0.6 percentage points in the fraction of full-term pregnancies.

In terms of cause of death, significant effects are concentrated on three main conditions: intestinal infections, malnutrition, and non-reported causes. The estimated impact on these three causes of death add up to roughly the total mortality effect estimated in Table 2, therefore exhausting the impact of rainfall variation. There is also some borderline significant impact on respiratory infections, but the magnitude of the coefficient is considerably smaller. This result is particularly important because, as discussed in section 2.2, intestinal infections (mainly diarrhoea), malnutrition, and respiratory infections are precisely the types of conditions that should be affected by water availability (World Health Organization (2012)). But malnutrition may also be related to nutrient intake and agricultural production. Though the coefficient for intestinal infections is considerably larger, indicating a potentially important role for reduced access to clean water, it is still possible that part of the effect estimated for malnutrition is due to lower agricultural production and food availability. In addition, since reporting of cause of death is deficient in some of the poor areas in our sample, the reduction in mortality by non-reported causes probably just reflects further reductions in one of other two main causes of death identified before. Overall, results are remarkably consistent with what should be expected from variations in water scarcity in a semiarid environment.

The last two columns in Table 3 dig a little deeper on the selection problem. Column 9 shows that rainfall variations also tend to be associated with number of births. Positive rainfall shocks are followed by a mild increase in the number of births. This increase seems to be homogeneous across boys and girls, with no change in sex-ratio at birth (see column 10). The typical concern with selection at birth is that fewer births mean that individuals being born are stronger and better fit. Here, when considering shocks that affect health during the gestation period, we observe higher selection (lower number of births) precisely when birth outcomes are worse (higher mortality, lower birth weight, and shorter gestations). As mentioned before, it is extremely unlikely here that parents are actively making fertility choices in anticipation of rainfall variations. Therefore, variation in number of births is probably just another dimension of health impacts from rainfall fluctuations, with water scarcity being associated with higher probability of miscarriages and lower probability of conception. It is still true that, with negative rainfall shocks and lower number of births, the births that are materialized are of better quality than those that are not. But, if anything, this selection tends to work against our results, since it generates a positive correlation between selection before birth and health outcomes.

The important point to come out of this is that, when talking about such extreme shocks in the gestation period, selection seems to be relatively unimportant vis-à-vis the overall effect of the shock itself on surviving children. Negative rainfall shocks that reduce the number of births and increase mortality also worsen the health of those who survive. This was already apparent in Figure 4, but reveals itself again in Table 3.

5.2 Gender Heterogeneity

Table 4 explores the gender specificity of the results from Tables 2 and 3. We run the complete specification for boys and girls separately, looking at infant mortality, birth weight, gestation length, mortality by cause of death, and number of births. To save on space, we present results only when the log of rainfall deviations is used as the independent variable. Qualitatively, the results for boys and girls separately tend to replicate the patterns previously found. Most interestingly, the coefficients on the birth outcomes regressions for girls are always larger than those for boys, while the coefficient on number of births is larger for boys. Though only in few cases the difference is statistically significant, this pattern is present in all columns in Table 4. It seems to be the case that health outcomes at and after birth for girls are more sensitive to rainfall variations in the gestation period than those for boys. In some cases – such as birth weight – this difference is substantial, while in others – such as gestation length or mortality by intestinal infections – it is less relevant.

It is difficult to think that gender bias on the part of parents accounts for these results, given that we are exploiting shocks during the gestational period in very poor areas, where in most cases it is even unlikely that the gender of the child is known before birth. In addition, gender bias at early ages is usually not thought to be a serious problem in Brazil. On face value, the quantitative results suggest that, before birth, boys are more fragile than girls. If that was the case, the impact of rainfall variation on the number of boys being born would be greater than that on the number of girls. And a higher number of girls surviving gestation could mean weaker girls being born. Though this logic is consistent with the results from Table 4, it is difficult to reconcile with the absence of an effect of rainfall on sex ratio at birth reported in Table 3.

Experimental research on medical sciences has detected gender specific effects of simulated water and famine conditions during pregnancy, even though the mechanism behind these effects are not understood (Ross and Desai (2005)). At the same time, Maccini and Yang (2009) have also found gender specific long term schooling effects of rainfall shocks. But they look at rainfall during the first year of life and find no effect at all for males. Put together this evidence suggests that gender heterogeneity in environmental shocks are probably the results of a combination of biological and social factors. In our setting, the biological dimension is likely to be the main driver. But further research on the topic is needed to clarify these connections. Given our focus, this effort is beyond the scope of this paper.

5.3 Timing

Another important aspect of the effect of water scarcity on birth outcomes is the specific timing of the impacts. The question of timing has at least three relevant dimensions: (i) the moment of water scarcity during the gestation period; (ii) the moment of water scarcity during the calendar year; and (iii) the moment after birth when the effect of water scarcity is felt. In addition to being interesting and relevant on their own, these dimensions of timing may also help understand the specific channels linking water scarcity and birth outcomes.

In Table 5, we explore the impact of variations in rainfall through the gestation period and through the calendar year. We focus on infant mortality as the dependent variable. In the first column, we run the same specification from column 4 in Table 2, but break down the log of rainfall deviation into variables indicating different quarters. These can be roughly classified as: before conception (one trimester before the beginning of pregnancy), embryogenesis (first trimester), fetal development (second trimester), and perinatal period (third trimester). In the second and third columns, we look only at children born during the rainy season (from January to June). We first look at the overall impact of rainfall deviations during pregnancy for these children, and then look at the effect by trimester of gestation. Finally, in columns 4 and 5, we repeat these exercises for children born during the dry season (from July to December). To save on space, in the remainder of the paper we focus on the log of rainfall deviations as our independent variable. Results are generally similar, but slightly less robust, when we run the same regressions with drought as the independent variable.

Column 1 shows that, when looking at all births, significant impacts appear only in the first and second trimesters of gestation, corresponding approximately to the periods of embryonic formation and fetal development. We estimate much smaller and non-significant coefficients for the last trimester of gestation and for the period before conception. When we further break down the analysis by rainy and dry seasons, an additional striking result becomes apparent. Comparing columns 2 and 4, one can see that the effect of rainfall variation on infant mortality is much stronger for children born in the dry season. For the case of the rainy season, the estimated coefficient is -3.2 and imprecisely estimated, while for the dry season it is -10.9 and statistically significant. The difference between the two estimated coefficients is also statistically significant.

Looking at the dry season, the main impacts are again concentrated on the first two trimesters of pregnancy. We find no significant effect in the last trimester, and a borderline significant effect for the trimester immediately before conception. Curiously, for the rainy season, we do find some statistically significant impact in the last trimester, but the effect is quantitatively smaller than the others reported in the table. None of the remainder coefficients are statistically significant for the rainy season regression.

This pattern of results confirms that we are capturing indeed the effect of water scarcity during the gestation period. In fact, the table highlights the relevance of availability of water during the moments of early development of the embryo and formation of organs (first two trimesters of gestation). The results related to births during the rainy and dry seasons suggest that access to clean drinkable water, per se, is the main driving force. For births in the dry season, a low precipitation in the previous 12 months means that the little reserves of water collected during the rainy season are, during pregnancy, already at low levels and, therefore, of poor quality. These would increase the probability of infectious diseases and dehydration for the mother, affecting the health of the fetus.

In Table 6, we look at the moment of realization of mortality. We analyze both overall variation in rainfall in the 12 months before birth and by trimester of gestation, and look at their effects on mortality in different time frames: (i) the first 24 hours of life; (ii) from 24 hours to 3 months; (iii) from 3 to 6 months; (iv) from 6 to 9 months; and (v) from 10 to 12 months.

Given the higher frequency of mortality being analyzed, some of the coefficients are estimated with less precision. Also, quantitative comparisons of the coefficient related to mortality in the first 24 hours should bear in mind that its time interval is much shorter than the other ones. The results indicate a borderline statistically significant coefficient for mortality during the first day of life, and statistically significant effects for mortality in the first 6 months of life. After 6 months, the coefficient becomes smaller in magnitude and ceases to be statistically significant. Consistent with the effects being concentrated in the first months of life, the coefficient drops even further when we look at the period between 10 and 12 months and remains non-significant.

Given the time interval, the coefficient in column 1 – related to mortality in the first day of life – is extremely large in magnitude, but imprecisely estimated (on a monthly basis, it would be of the order of -30). The profile of results, therefore, suggests that the effects of rainfall during gestation are concentrated in the period immediately after birth, and tend to become less relevant as the child survives the first six months of life. Once more, this reinforces the evidence that the conditions faced in utero – and not after birth – are indeed the driving force behind our results. The results broken down by trimester of gestation in Table 6 show again that the fetal development period (second trimester) seems particularly important, with significant effects appearing also in the embryogenesis period (first trimester) for mortality in the first 3 months of life.

Despite the absence of mortality impacts after six months of life, the effects detected in Table 2 on birth weight and length of gestation suggest that water scarcity can still have long-run impacts on morbidity and cognitive development. These are extremely relevant possibilities, but that are again beyond the scope of this paper. The authors explore this issue in a companion piece (Rocha and Soares (2011)).

5.4 Channels

Our final effort in this paper is to present further evidence on the specific channels linking variation in rainfall to health outcomes at birth. In the context of the Brazilian semiarid, there are two main potential connections in this relationship. First, water scarcity may be associated with lower agricultural production and, therefore, lower nutrient intake. Second, it may be associated with lack of access to safe drinkable water and, therefore, higher incidence of infectious diseases. The evidence presented up to now suggests that lack of access to safe drinkable water is likely to be an important factor, but still leaves space for some effect through agricultural production.

In order to address this issue more directly, Table 7 presents two sets of exercises. First, in Panel A, we run the benchmark specification from column 4 in Table 2 controlling for municipality agricultural production per capita. In the first column, we control for agricultural production in the 12 months before birth, the same time frame used for our rainfall variable. In the second column, we control for agricultural production in the period between 12 and 24 months before birth (year before conception), while in column 3 we control for agricultural production in the first year of life. Finally, in column 4, we include the three agricultural production variables simultaneously.[5]

The results are striking. Irrespective of how we introduce agricultural production in the regression, there is virtually no change in the coefficient associated with rainfall before birth. The coefficient actually increases mildly in magnitude when the three agricultural production variables are included simultaneously. Agricultural production, in turn, does not appear as

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[5] Our agricultural production data have, in reality, an yearly frequency. We construct monthly data based on the weighted average of production across consecutive years. So, for example, for an individual born in March, agricultural production in the 12 months prior to birth will be 0.3 times agricultural production in the year of birth plus 0.7 times agricultural production in the year before birth. Though this is only a rough approximation to the actual production during the relevant months, it does capture movements in agricultural production around the time of birth. Issues of the specific timing of production are dealt with in column 4 of the table, where we introduce agricultural production in the three consecutive years around birth simultaneously.

statistically significant. Panel A suggests that the estimated impact of rainfall variation on health at birth is not driven by local agricultural production and nutrient availability.

In Panel B, we look at the heterogeneity of effect by municipality characteristics. The literature on access to water highlights that water scarcity should be a particularly serious health issue when sanitation and water services are poorly developed. To evaluate whether this link is present in our results, in column 1 we interact rainfall before birth with municipality coverage of public water services. In column 2, we repeat the same exercise for sanitation coverage. Still, it is possible that sanitation and piped water are just capturing the overall level of development in the municipality. So, in column 3, we repeat again the same exercise using municipality income per capita and, in column 4, we include the three interaction terms simultaneously.

Columns 1 to 3 show a similar pattern for the three municipality characteristics analyzed. There is a negative impact of rainfall variation on infant mortality, but this effect is reduced for municipalities with higher coverage of piped water, converging to close to zero as water coverage reaches 100%. Exactly the same pattern is true for sanitation coverage and income per capita. These first results suggest that municipalities with better public health infrastructure and higher income per capita are less subject to variations in mortality due to rainfall shocks. But this pattern is consistent both with a direct effect of public health infrastructure and with an effect of overall economic development.

When we look at the three interaction terms simultaneously, in column 4, none of them is separately significant. This should be expected, given the high degree of collinearity among them. Still, the net effects calculated from column 4 are very enlightening. We have three dimensions of variation here, so net effects should be calculated conditional on a certain fraction of piped water and sanitation coverages, and on a given level of income per capita. In order to summarize the results, Table 8 calculates the net effect of rainfall variation on infant mortality at different levels of the three municipality characteristics. Panel A is conditioned on income per capita at the 25^{th} percentile of the distribution, Panel B on income per capita at the 50^{th} percentile, and Panel C at the 75^{th} percentile. Within each panel, rows indicate different fractions of households covered by public sanitation and columns indicated coverage of piped water (from 0% to 100%). Moving from panel to panel, one can see how the effect of rainfall variation changes with income per capita, for given levels of piped water and sanitation coverage. Moving within a panel across columns, one can see how the effect changes with piped water coverage, for given levels of sanitation and income per capita. And moving across rows, one can see how the effect changes with sanitation coverage, for given piped water coverage and income per capita.

The first thing to come out of the table is that, though higher income seems to be associated with lower impact of rainfall variation – as when we move from Panel A to Panel C – the heterogeneity is very mild when compared to changes in sanitation and piped water coverages. In other words, the within panel variation in net effects is much larger than the across panel variation. For example, municipalities with 40% coverages of piped water and sanitation have a net effect of -10.55 if they are on the 25th percentile of income per capita, and of -8.50 if they are on the 75th percentile.

The joint effect of piped water and sanitation coverages is, in contrast, much larger. For municipalities with the median income per capita, a movement in coverage of sanitation and water from 20% to 80% leads to a reduction in the net effect of rainfall variation from -11.46 to -5.95 (and only borderline statistically significant). Similar patterns are observed for other levels of income per capita. A sufficiently high coverage of piped water seems to be, in isolation, the most important factor in determining reductions in the impact of rainfall variation. Irrespective of income per capita or sanitation, access to piped water has a substantial impact on the sensitivity to rainfall shocks. Still, it is true that the effects of access to water and sanitation combined lead to the greatest reductions in the responsiveness of infant mortality to rainfall.

These results are remarkably consistent with a vast literature on the health impacts of access to water (see, for example, Mara (2003), United Nations Development Programme (2006), Fewtrell et al. (2007), World Health Organization (2010), World Health Organization (2012), Pond et al. (2011)). All this body of work highlights that the health implications of poor access to water should be particularly strong in contexts of poor coverage of sanitation and water services. The pattern encountered in Table 8, therefore, reassures that the results obtained before are indeed driven by the effect of access to safe drinkable water, per se, on birth outcomes. We do seem to be able to isolate the effect of water scarcity during the gestation period on outcomes at birth.

6 Concluding Remarks

SOME QUANTITATIVE EXERCISES WITH HISTORICAL SHOCKS

The second set of results relates to the stream of literature that studies the relationship between weather and development. This paper provides statistically significant evidence on a negative relationship between adverse rainfall fluctuations and a range of infant health indicators, as measured by birth weight, gestation length and infant mortality rates per cause of death. Importantly, we find substantial impacts. This set of results suggests that maternal health should be a priority focus of policy interventions during episodes of adverse natural phenomena.

References

Ab'Sáber, A. (1999). Sertões e Sertanejos: uma Geografia Humana Sofrida. *Estudos Avancados*, 13:7–59.

Aguilar, A. and Vicarelli, M. (2011). El Nino and Mexican Children: Medium-term Effects of Early-Life Weather Shocks on Cognitive and Health Outcomes. Unpublished Manuscript.

Almond, D. and Currie, J. (2010). Human Capital Development Before Age Five. NBER Working Paper n. 15827.

Áridas, P. (1995). *Nordeste: Uma Estratégia de Desenvolvimento Sustentável.* Ministerio da Integracao Nacional.

Barker, D. (1998a). In Utero Programming of Chronic Disease. *Clinical Science*, 95(2):115–128.

Barker, D. (1998b). *Mothers, Babies, and Health in Later Life.* Elsevier Health Sciences.

Barron, W. (1987). Water Metabolism and Vasopressin Secretion During Pregnancy. *Baillière's Clinical Obstetrics and Gynaecology*, 1(4):853.

Black, R., Allen, L., Bhutta, Z., Caulfield, L., De Onis, M., Ezzati, M., Mathers, C., and Rivera, J. (2008). Maternal and Child Undernutrition: Global and Regional Exposures and Health Consequences. *Lancet*, 371(9608):243–260.

Bloomfield, F. and Harding, J. (1998). Experimental Aspects of Nutrition and Fetal Growth. *Fetal and Maternal Medicine Review*, 10(02):91–107.

Bloomfield, F., Oliver, M., and Harding, J. (2006). The Late Effects of Fetal Growth Patterns. *British Medical Journal*, 91(4):F299.

Bozzoli, C., Deaton, A., and Quintana-Domeque, C. (2009). Adult Height and Childhood Disease. *Demography*, 46(4):647–669.

Brown, K. and Dewey, K. (1992). *Mechanisms Regulating Lactation and Infant Nutrient Utilization*, chapter Relationships Between Maternal Nutritional Status and Milk Energy Output of Women in Developing Countries, pages 99–77. New York: Wiley-Liss.

Burgess, R., Deschenes, O., Donaldson, D., and Greenstone, M. (2011). Weather and Death in India. Unpublished Manuscript.

Campos, J. N. B. (1994). *Vulnerabilidade do Semi-Arido as Secas Sob o Ponto de Vista dos Recursos Hidricos*. Projeto Aridas.

Cirilo, J. (2008). Políticas Públicas de Recursos Hídricos para o Semi-árido. *Estudos Avançados*, 22(63):61.

Currie, J. (2009). Healthy, Wealthy, and Wise: Socioeconomic Status, Poor Health in Childhood, and Human Capital Development. *Journal of Economic Literature*, 47(1):87–122.

Deschenes, O., Greenstone, M., and Guryan, J. (2009). Climate Change and Birth Weight. *American Economic Review: Papers and Proceedings*, 99(2):211–217.

Deschenes, O. and Moretti, E. (2009). Extreme Weather Events, Mortality, and Migration. *The Review of Economics and Statistics*, 91(4):659–681.

Fewtrell, L., Prüss-Üstün, A., Bos, R., Gore, F., Bartram, J., et al. (2007). Water, Sanitation and Hygiene: Quantifying the Health Impact at National and Local Levels in Countries with Incomplete Water Supply and Sanitation Coverage. *WHO Environmental Burden of Disease Series*, (15).

Friedman, G. (1982). The Heights of Slaves in Trinidad. *Social Science History*, 6(4):482–515.

Glewwe, P. W. and Miguel, E. A. (2008). The Impact of Child Health and Nutrition on Education in Less Developed Countries. In Schultz, T. P. and Strauss, J. A., editors, *The Handbook of Development Economics*, volume 4, chapter 56, pages 3561–3606. Elsevier, 1 edition.

Gorgens, T., Meng, X., and Vaithianathan, R. (2011). Stunting and Selection Effects of Famine: A Case Study of the Great Chinese Famine. *Journal of Development Economics*. Forthcoming.

Kim, Y. (2010). The Impact of Rainfall on Early Child Health. Unpublished Manuscript.

Kudamatsu, M., Persson, T., and Stromberg, D. (2010). Weather and Infant Mortality in Africa. Unpublished Manuscript.

Linnet, K., Wisborg, K., Agerbo, E., Secher, N., Thomsen, P., and Henriksen, T. (2006). Gestational Age, Birth Weight, and the Risk of Hyperkinetic Disorder. *Archives of Disease in Childhood*, 91(8):655.

Luna, R. M. (2007). Desenvolvimento do Indice de Pobreza Hidrica (IPH) para o Semiarido Brasileiro. Master's thesis, Universidade Federal do Ceara.

Maccini, S. and Yang, D. (2009). Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall. *American Economic Review*, 99(3):1006–1026.

Mara, D. (2003). Water, Sanitation and Hygiene for the Health of Developing Nations. *Public Health*, 117(6):452–456.

Matsuura, K. and Willmott, C. (2009). Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02. University of Delaware.

Morgane, P., Austin-LaFrance, R., Bronzino, J., Tonkiss, J., Diaz-Cintra, S., Cintra, L., Kemper, T., and Galler, J. (1993). Prenatal Malnutrition and Development of the Brain. *Neuroscience & Biobehavioral Reviews*, 17(1):91–128.

Parry, M., Canziani, O., Palutikof, J., Van Der Linden, P., and Hanson, C. (2007). *IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, UK.

Pond, K., Pedley, S., and Edwards, C. (2011). *Background Chapter In: Cameron, J. and Hunter, P. and Jagals, P. and Pond, K., Valuing Water, Valuing Livelihoods.* London: IWA Publishing.

Rebouças, A. (1997). Água na Região Nordeste: Desperdício e Escassez. *Estudos Avançados*, 11(29):127–154.

Rocha, R. and Soares, R. (2011). Early Life Health and Educational Performance: Evidence From Rainfall Fluctuations in the Brazilian Northeast. Unpublished Manuscript.

Ross, M. and Desai, M. (2005). Gestational programming: Population survival effects of drought and famine during pregnancy. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 288(1):R25–R33.

Shenkin, S., Starr, J., and Deary, I. (2004). Birth Weight and Cognitive Ability in Childhood: a Systematic Review. *Psychological Bulletin*, 130:989–1011.

Skoufias, E., Vinha, K., and Conroy, H. (2011). The Impacts of Climate Variability on Welfare in Rural Mexico. *World Bank Policy Research Working Paper*, 5555.

Sobsey, M. (2002). *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*. World Health Organization.

Steegers-Theunissen, R. (1995). Maternal Nutrition and Obstetric Outcome. *Baillière's Clinical Obstetrics and Gynaecology*, 9(3):431–443.

SUDENE (1981). *As Secas do Nordeste: Uma Abordagem Historica de Causas e Efeitos*. SUDENE, Ministerio do Interior.

SUDENE (2008). Nova Delimitacao da Regiao Semi-arida do Brasil. SUDENE, Recife.

Suliano, D., Magalhaes, K., and Soares, R. (2009). A Infuencia do Clima no Desempenho da Economia Cearense. IPECE, Texto para Discusso n.56.

United Nations Development Programme (2006). *Human Development Report 2006. Beyond Scarcity: Power, Poverty and the Global Water Crisis*. Palgrave Macmillan.

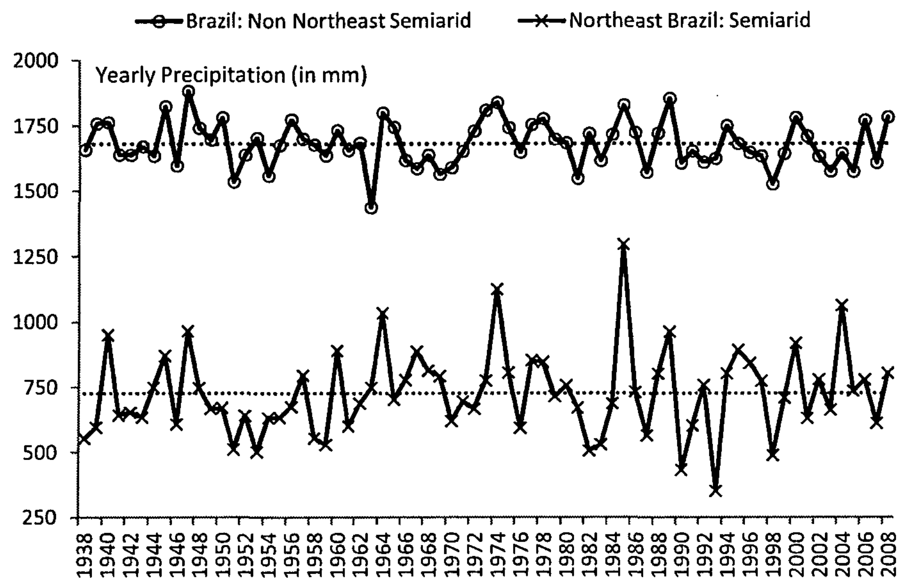
Villa, M. (2000). *Vida e Morte no Sertao: Historias das Secas no Nordeste nos Seculos XIX e XX*. Atica.

World Bank (2008). *World Development Report 2008: Agriculture For Development*. World Bank, Washington.

World Health Organization (2010). *UN-Water Global Annual Assessment of Sanitation and Drinking-water: GLAAS 2010: Targeting Resources for Better Results*. World Health Organization, Geneva.

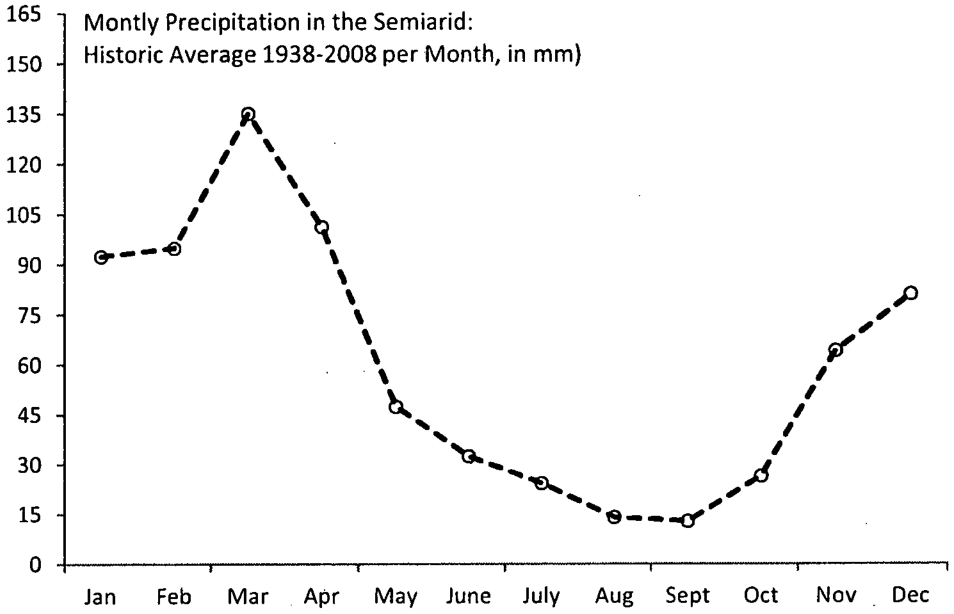
World Health Organization (2012). *Drought: Natural Disaster Profiles*. World Health Organization, Geneva.

Figure 1 - Yearly Precipitation in Brazilian Semiarid Northeast and in the Rest of the Country



Notes: Author's calculation based on data from the Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02.

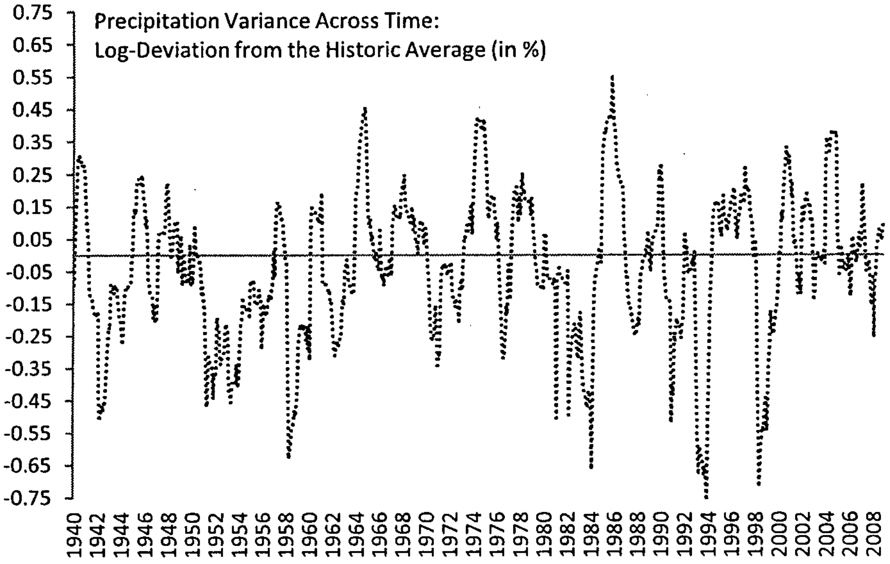
Figure 2 - Monthly Rainfall in the Brazilian Semiarid Northeast, Historical Averages



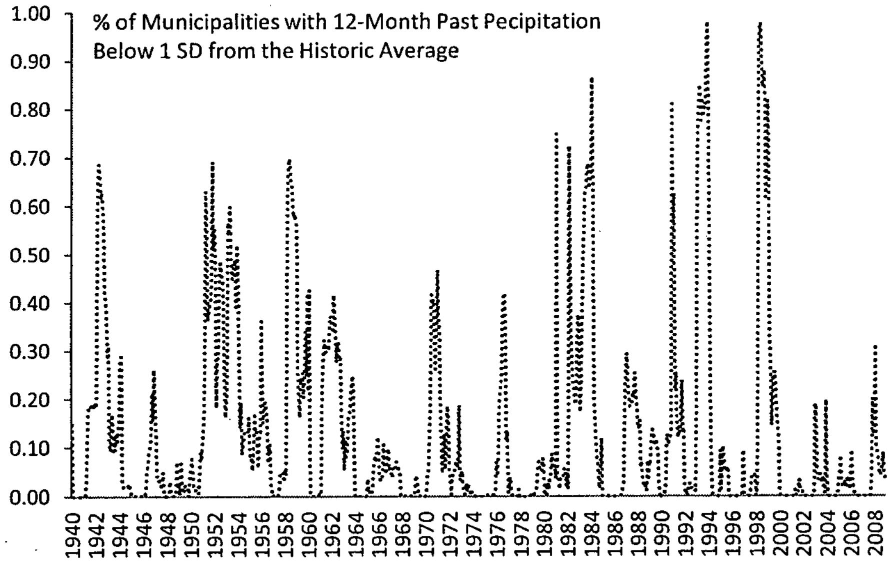
Notes: Municipality averages. Author's calculation based on data from the Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02.

Figure 3 - Rainfall Idiosyncratic Fluctuations Across Time and Place in the Northeast Semiarid

Panel A - Deviation of Log Rainfall in the Past 12 Months from the Avg.

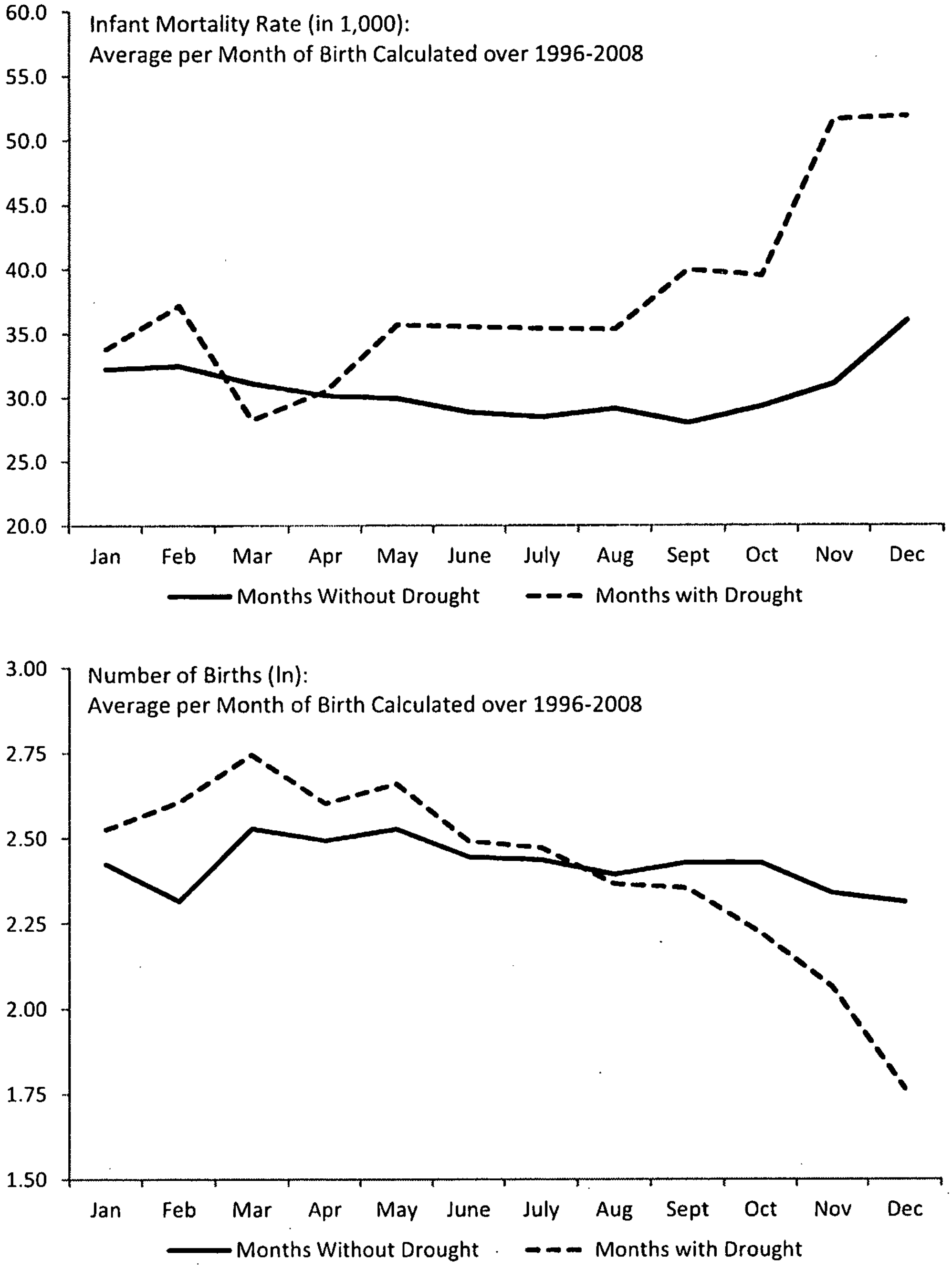


Panel B - Drought Indicator (Rainfall in the Past 12 Months Below 1 SD the Avg.)



Notes: Municipality averages. Author's calculation based on data from the Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02.

Figure 4 - Seasonal Infant Mortality and Fertility: Drought vs Non Drought Month of Birth



Notes: Municipality averages. Author's calculation based on data from the Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02.

Table 1 - Summary Statistics: Infant Health and Mortality Rates Across Municipalities, Monthly Data Over the Period 1996-2008

Variables	Mean	Std. Deviation	Min	Max	Number of Municipalities	Number of Observations
Births and Health Indicators per Month of Birth:						
Number of Births	28.9	52.4	0	1117	1048	163488
Birth Weight	3271	207	300	5281	1048	157222
% of Births Occurring after 36 Weeks of Gestation	0.94	0.13	0	1	1048	157200
Number of Infant Deaths	0.84	2.05	0	72	1048	163488
Infant Mortality per Month of Birth (up to age 1, per 1,000):						
Total Infant Mortality	31.26	82.63	0	1000	1048	157403
Intestinal Infections	3.67	29.51	0	1000	1048	157403
Malnutrition	1.09	16.48	0	1000	1048	157403
Pneumonia and Respiratory Infections	1.97	21.48	0	1000	1048	157403
Affections of Perinatal Origin	14.02	51.88	0	1000	1048	157403
Congenital Malformations	2.28	20.56	0	1000	1048	157403
Non Reported Causes	7.37	45.89	0	1000	1048	157403
Rainfall Indicators per Month:						
Rainfall in the Past 12 Months (in mm)	800.3	256.8	80.89	2299.4	1048	163488
Rainfall Log-Deviation in the Past 12 Months	0.022	0.2963	-1.774	0.9609	1048	163488
Drought in the Past 12 Months	0.097	0.2964	0	1	1048	163488

Notes: Monthly observations by municipality, from 1996 to 2008. Data originally from: (i) the Brazilian National System of Information on Birth Records (Datasus/SINASC); (ii) the Brazilian National System of Mortality Records (Datasus/SIM); and (iii) the *Terrestrial Air Temperature and Precipitation: 1900-2008 Gridded Monthly Time Series, Version 1.02* (Matsuura and Willmott (2009)).

Table 2 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations on Infant Mortality Rates

	(1)	(2)	(3)	(4)	(5)
			Panel A - Rainfall		
Rainfall before Birth	-4.486	-4.759	-7.034	-7.139	-8.405
	(1.290)***	(1.297)***	(1.642)***	(1.828)***	(2.438)***
Rainfall 12-24 Months before Birth					-1.878
					(2.368)
Rainfall 1-12 Months after Birth					-3.370
					(2.700)
			Panel B - Drought		
Drought before Birth	2.087	2.265	3.984	3.761	4.594
	(1.118)*	(1.109)**	(1.299)***	(1.324)***	(1.620)***
Rainfall 12-24 Months before Birth					-0.771
					(2.327)
Rainfall 1-12 Months after Birth					-2.224
					(2.469)
Observations	157,403	155,688	155,688	155,688	143,319
Number of Municipalities	1.048	1.037	1.037	1.037	1.037
Municipality × Month of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Grid Time Trend	Yes	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	No	Yes	Yes	Yes	Yes
Weighted (Average Number of Newborns)	No	No	Yes	Yes	Yes
Temperature before Birth	No	No	No	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variable is infant mortality (up to age 1) per 1,000 births, calculated at the municipality level by month of birth. Independent variable in Panel A is rainfall log-deviation in past 12 months and in Panel B dummy indicating drought in past 12 months. All regressions include municipality by month of birth fixed effects and year of birth fixed effects. Additional controls included in some specifications are: grid-specific linear time trends, average temperature in 12 months before birth, rainfall in 12-24 months before birth, and rainfall in 0-12 months after birth. Columns 3-6 exclude municipalities with average number of births per month in the top 1%. Regressions in columns 4-6 are weighted by municipality average number of births per month.

Table 3 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations on Births, Maternal and Infant Health, and Infant Mortality by Cause of Death

	Birth Weight	Gestation >37 weeks	Infant Mortality Rate per Cause of Death						ln(Number of Births)	Sex Ratio
			Intestinal	Malnutrition	Respiratory	Perinatal	Congenital	Non Reported		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					Panel A - Rainfall					
Rainfall before Birth	6.462	0.019	-3.877	-1.289	-0.814	-1.707	0.014	-2.148	0.059	0.001
	(2.607)**	(0.003)***	(0.897)***	(0.430)***	(0.458)*	(1.065)	(0.281)	(0.747)***	(0.029)**	(0.002)
					Panel B - Drought					
Drought before Birth	-4.348	-0.010	2.250	0.346	0.585	0.706	-0.075	0.953	-0.053	-0.000
	(2.127)**	(0.003)***	(0.591)***	(0.198)*	(0.335)*	(0.807)	(0.223)	(0.570)*	(0.023)**	(0.001)
Observations	155,507	155,485	155,688	155,688	155,688	155,688	155,688	155,688	161,772	155,688
Number of Municipalities	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037
Municipality × Month of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variables are: average number of births per month, sex ratio at birth, average birth weight, fraction of births with complete gestation, and infant mortality (up to age 1) by cause of death. Independent variable in Panel A is rainfall log-deviation in past 12 months and in Panel B dummy indicating drought in past 12 months. All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month.

Table 4 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations on Infant Health by Gender

	Infant Mortality	Birth Weight	Gestation >37 weeks	Infant Mortality Rate per Cause of Death							ln(Number of Births)
				Intestinal	Malnutrition	Respiratory	Perinatal	Congenital	Non Reported	
	(1)	(2)	(3)	(4)	(6)	(7)	(8)	(9)	(10)	(11)
				Panel A - Boys						
Rainfall before Birth	-6.080	1.974	0.018	-2.234	-0.558	-0.428	-0.465	0.310	-1.957	0.062
	(1.526)***	(3.025)	(0.003)***	(0.705)***	(0.296)*	(0.428)	(0.911)	(0.305)	(0.900)**	(0.032)**
Observations	151,691	151,361	151,265	151,691	151,691	151,691	151,691	151,691	151,691	161,772
				Panel B - Girls						
Rainfall before Birth	-9.067	10.614	0.019	-3.231	-1.110	-0.567	-2.126	-0.333	-2.440	0.051
	(1.636)***	(3.096)***	(0.003)***	(0.745)***	(0.403)***	(0.355)	(0.815)***	(0.313)	(0.760)***	(0.031)
Observations	151,145	150,815	150,715	151,145	151,145	151,145	151,145	151,145	151,145	161,772
Number of Municipalities	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037
Municipality × Month of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variables are: average number of births per month, sex ratio at birth, average birth weight, fraction of births with complete gestation, and infant mortality (up to age 1) by cause of death. Independent variable in Panel A is rainfall log-deviation in past 12 months and in Panel B dummy indicating drought in past 12 months. All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month.

Table 5 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations by Trimester of Gestation and Season

	Mortality				
	(1)	(2)	(3)	(4)	(5)
	All Year (Jan-Dec)	Born in Rainy Season (Jan-June)		Born in Dry Season (July-Dec)	
Rainfall before Birth		-3.235		-10.922	
		(2.345)		(3.092)***	
Rainfall by Trimester of Gestation:					
3rd Trimester (Perinatal)	0.049		-1.680		0.343
	(0.383)		(0.675)**		(0.535)
2nd Trimester (Fetal)	-2.147		-0.751		-2.506
	(0.501)***		(0.402)*		(0.963)***
1st Trimester (Embryonic)	-0.751		-0.115		-2.332
	(0.274)***		(0.279)		(0.787)***
Trimester before Conception	-0.162		0.048		-1.103
	(0.303)		(0.536)		(0.648)*
Observations	155,688	77,925	77,925	77,763	77,763
Number of Municipalities	1.037	518	518	518	518
Municip × Month of Birth FE	Yes	Yes	Yes	Yes	Yes
Year of Birth FE	Yes	Yes	Yes	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes	Yes	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variables are infant mortality (up to age 1) and average number of births per month. Independent variables are rainfall log-deviation by trimester of gestation and season of birth: rainfall fluctuation per trimester calculated as deviations of the sum of rainfall in each trimester from its historical average; columns 3-6 include only children born from January to June (rainy season); columns 7-10 include those born from July to December (dry season). All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month.

Table 6 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations by Trimester of Gestation and Timing of Death

	in 24 hrs		24hrs to 3 months		3 to 6 months		6 to 9 months		10 to 12 months	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Rainfall before Birth	-1.094		-3.730		-2.698		-0.772		-0.112	
	(0.604)*		(0.899)***		(0.892)***		(0.513)		(0.223)	
Rainfall by Trimester of Gestation:										
3rd Trimester (Perinatal)		-0.234		0.297		-0.049		0.088		-0.056
		(0.198)		(0.154)*		(0.239)		(0.178)		(0.033)*
2nd Trimester (Fetal)		-0.776		-0.870		-1.040		-0.190		-0.029
		(0.287)***		(0.368)**		(0.333)***		(0.106)*		(0.056)
1st Trimester (Embryonic)		-0.049		-0.542		-0.188		-0.048		-0.022
		(0.130)		(0.180)***		(0.177)		(0.090)		(0.066)
Trimester before Conception		-0.057		-0.278		0.050		-0.052		0.082
		(0.109)		(0.156)*		(0.125)		(0.103)		(0.075)
Observations	155,688	155,688	155,688	155,688	155,688	155,688	155,688	155,688	155,688	155,688
Number of Municipalities	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037
Municip × Month of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variable is infant mortality (up to age 1) by timing of death (in months). Independent variables are rainfall log-deviation by trimester of gestation and season of birth: rainfall fluctuation per trimester calculated as deviations of the sum of rainfall in each trimester from its historical average; columns 3-6 include only children born from January to June (rainy season); columns 7-10 include those born from July to December (dry season). All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month.

Table 7 - Fixed-Effects Panel Regressions: Channels in the Impact of Rainfall Fluctuations on Infant Mortality

	Infant Mortality Rate			
	(1)	(2)	(3)	(4)
	Panel A			
Rainfall before Birth	-7.003	-7.271	-7.616	-7.700
	(1.799)***	(1.868)***	(2.145)***	(2.182)***
Agricultural Production before Birth	-0.431			-0.459
	(0.785)			(0.852)
Agricultural Production 12-24 Months before Birth		-0.675		-0.822
		(0.807)		(0.854)
Agricultural Production 1-12 Months after Birth			0.826	0.987
			(1.087)	(1.124)
Observations	155,666	155,673	143,297	143,292
Number of Municipalities	1.037	1.037	1.037	1.037
	Panel B			
Rainfall before Birth	-15.648	-14.934	-48.783	-37.808
	(3.117)***	(3.373)***	(13.969)***	(17.478)**
Rainfall before Birth × % Water Coverage	14.384			6.411
	(4.745)***			(6.255)
Rainfall before Birth × % Sanitation Coverage		14.611		2.764
		(5.472)***		(8.125)
Rainfall before Birth × ln(Income per Capita)			9.215	5.619
			(3.040)***	(4.462)
Observations	155,688	155,549	155,688	155,549
Number of Municipalities	1.037	1.036	1.037	1.036
Municip × Month of Birth FE	Yes	Yes	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes	Yes	Yes
Sample: % of Rural Households	All	All	All	All

Notes: Robust standard errors clustered at the grid level. Significance: *** p < 0.01, ** p < 0.05, * p < 0.1. Dependent variable is infant mortality (before age 1). Independent variable is rainfall log-deviation in past 12 months. In Panel A, agricultural production control is log of weighted average of the value of agricultural production per capita in the year of birth (calendar month of birth/12) and the previous year ((12 - calendar month of birth)/12). Lagged and lead values are calculated analogously. In Panel B, rainfall before birth is interacted with: municipality share of households with water and sanitation coverage, and log of the income per capita (calculated from the 2000 Census files). All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month. In column 5, sample restricted to municipalities with more than 50% of households in rural areas (calculated from 2000 Census files).

Table 8 - Heterogeneous Effects of Rainfall Variation on Infant Mortality, by Income p.c., Water and Sanitation Coverage (Based on Coefficients from Table 8, Column 4 in Panel B)

Panel A - Income p.c. at the 25th percentile

		% Water Coverage					
		0	0.2	0.4	0.6	0.8	1
% Sanitation Coverage	0	-14.22	-12.94	-11.65	-10.37	-9.09	-7.81
		(14.21)***	(13.22)***	(9.55)***	(5.69)**	(3.09)*	(1.62)
	0.2	-13.67	-12.38	-11.10	-9.82	-8.54	-7.26
		(19.77)***	(23.82)***	(18.79)***	(9.83)***	(4.50)**	(2.05)
	0.4	-13.11	-11.83	-10.55	-9.27	-7.98	-6.70
		(17.29)***	(25.46)***	(26.61)***	(14.32)***	(5.83)**	(2.36)
	0.6	-12.56	-11.28	-10.00	-8.71	-7.43	-6.15
		(10.03)***	(12.93)***	(14.10)***	(10.18)***	(5.04)**	(2.15)
	0.8	-12.01	-10.73	-9.44	-8.16	-6.88	-5.60
		(5.38)**	(5.91)**	(5.84)**	(4.69)**	(2.91)*	(1.46)
	1	-11.45	-10.17	-8.89	-7.61	-6.33	-5.04
		(3.04)*	(3.01)*	(2.75)*	(2.21)	(1.49)	(0.83)

Panel B - Income p.c. at the 50th percentile

		% Water Coverage					
		0	0.2	0.4	0.6	0.8	1
% Sanitation Coverage	0	-13.29	-12.01	-10.73	-9.45	-8.17	-6.88
		(10.33)***	(9.63)***	(7.20)***	(4.44)**	(2.44)	(1.25)
	0.2	-12.74	-11.46	-10.18	-8.89	-7.61	-6.33
		(14.62)***	(17.43)***	(14.59)***	(8.08)***	(3.71)*	(1.63)
	0.4	-12.19	-10.91	-9.62	-8.34	-7.06	-5.78
		(14.32)***	(22.16)***	(26.54)***	(14.67)***	(5.46)**	(2.01)
	0.6	-11.64	-10.35	-9.07	-7.79	-6.51	-5.22
		(9.07)***	(12.64)***	(15.93)***	(12.18)***	(5.34)**	(1.95)
	0.8	-11.08	-9.80	-8.52	-7.24	-5.95	-4.67
		(4.96)**	(5.69)**	(5.99)**	(4.99)**	(2.95)*	(1.31)
	1	-10.53	-9.25	-7.97	-6.68	-5.40	-4.12
		(2.78)*	(2.80)*	(2.60)	(2.10)	(1.37)	(0.69)

Panel C - Income p.c. at the 75th percentile

		% Water Coverage					
		0	0.2	0.4	0.6	0.8	1
% Sanitation Coverage	0	-12.17	-10.89	-9.61	-8.33	-7.05	-5.76
		(6.73)***	(6.17)**	(4.72)**	(3.01)*	(1.68)	(0.85)
	0.2	-11.62	-10.34	-9.06	-7.78	-6.49	-5.21
		(9.29)***	(10.38)***	(8.93)***	(5.40)**	(2.58)	(1.10)
	0.4	-11.07	-9.79	-8.50	-7.22	-5.94	-4.66
		(9.94)***	(14.41)***	(17.66)***	(11.16)***	(4.21)**	(1.43)
	0.6	-10.52	-9.23	-7.95	-6.67	-5.39	-4.11
		(7.18)***	(10.30)***	(14.75)***	(12.98)***	(5.10)**	(1.52)
	0.8	-9.96	-8.68	-7.40	-6.12	-4.84	-3.55
		(4.18)**	(4.96)**	(5.61)**	(5.02)**	(2.82)*	(1.03)
	1	-9.41	-8.13	-6.85	-5.56	-4.28	-3.00
		(2.37)	(2.41)	(2.29)	(1.85)	(1.13)	(0.48)

Notes: F statistics for joint significance in parenthesis: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Each coefficient in represents the overall marginal effect of the log-deviation of rainfall in the 12 months before birth on infant mortality, for given levels of income p.c., and household water and sanitation converage. The coefficients (direct and interaction effects) and standard-errors used in the calculations correspond to the specification displayed in Table 8, Column 4 of Panel B.

Appendix Table A.1 - Fixed-Effects Panel Regressions: Impact of Rainfall Fluctuations on Infant Mortality and Number of Births by Precipitation Thresholds

	Infant Mortality	ln(Number of Births)
	(1)	(2)
Total Rainfall before Birth:		
Up to 400 mm	8.534	-0.177
	(2.725)***	(0.058)***
400 mm to 600 mm	5.774	-0.047
	(2.105)***	(0.030)
600 mm to 800 mm	2.643	-0.014
	(2.040)	(0.027)
800 mm to 1000 mm	3.534	-0.074
	(2.016)*	(0.031)**
1000 mm to 1200 mm	-1.181	-0.033
	(2.065)	(0.023)
Observations	155.688	161,772
Number of Municipalities	1.037	1.037
Municip × Month of Birth FE	Yes	Yes
Year of Birth FE	Yes	Yes
Temperature Control and Grid Trends	Yes	Yes
Exclude Top 1% in Number of Births	Yes	Yes
Weighted (Average N. of Newborns)	Yes	Yes

Notes: Robust standard errors clustered at the grid level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Dependent variables are infant mortality (up to age 1) and average number of births per month. Independent variables are dummies indicating total amount of rainfall (in mm) in past 12 months. All regressions include municipality by month of birth fixed effects, year of birth fixed effects, grid-specific linear time trends, average temperature in 12 months before birth, exclude municipalities with average number of births per month in the top 1%, and are weighted by municipality average number of births per month.

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