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Abstract*

This paper attempts to identify the climatic effect on birth outcomes in Brazil and, thus, to predict the potential impact of climate change. Panel data models indicate that excess and lack of rainfall have the most important harmful effects on newborns' health; temperature stresses and low relative humidity also have effects. The use of climate change forecasts for Brazil suggests a possible increase of 305 neonatal deaths annually and, for families in the Primary Care Program, three thousand additional low-weight births each year. The paper further examines public policy's role in minimizing the effects of extreme weather. Mothers' education, sanitation access and health care assistance to pregnant women represent the main instruments for addressing neonatal health problems.

JEL classifications: I12, I18, Q54
Keywords: Neonatal mortality, Health economics, Panel data, Climate change impacts on health

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1. Introduction

The current climate change discussion is no longer on the existence of climate change, but rather the magnitude of its longer-term impacts and measures for adaptation. According to Brazil's National Institute for Space Studies (INPE, 2011), the future risk of extreme events will increase with global warming, as Table 1 shows.

Table 1. Forecasts of Climate Change and Extreme Events by Region of Brazil, 2100

Region	Change in Temperature		Change in rainfall	
	Optimistic Scenario B2	Pessimistic Scenario A2	Optimistic Scenario B2	Pessimistic Scenario A2
North	3-5 °C warmer	4-8 °C warmer	5-15% Reduction of precipitation	15-20% Reduction of precipitation
South	1-3 °C warmer	2-4 °C warmer	0-5% Reduction of precipitation	5-15% Reduction of precipitation
Southeast	2-3 °C warmer	3-4 °C warmer	Increase in intensity and decrease in regularity of rain	Increase in intensity and decrease in regularity of rain
Midwest	2-4 °C warmer	3-6 °C warmer	Increase in intensity and decrease in regularity of rain	Increase in intensity and decrease in regularity of rain
Northeast	1-3 °C warmer	2-4 °C warmer	10-15% Reduction of precipitation	15-20% Reduction of precipitation

Source: INPE (2011).

One of the dimensions of extreme events' impact is human health. Climate-sensitive health problems kill millions of people every year and undermine the physical and psychological welfare of millions more. Additionally, extreme events tend to strike the poorest and most vulnerable people (WHO, 2012). When it comes to infants' health, there is a growing body of epidemiological literature studying the relationship between exposure to extreme weather (such as heat waves and cold waves, droughts and floods) during pregnancy and the early days of life, and birth outcomes (Murray et al., 2000; Lawlor, Leon and Smith, 2005).

The commonly used indicators for birth outcomes are low birthweight (LBW), as a proxy for the fetal experience in utero, and the neonatal mortality rate (NMR), which counts the deaths of infants within the first 27 days of life. LBW[1] normally results from premature birth or low intrauterine fetal growth rate due to different reasons (Black et al., 2007). These metrics reflect a

[1] The literature normally assumes the critical value for low birthweight as 2,500 g (Alexander et al., 1999; Phelan et al., 1998).

combination of factors that influence the health of babies: not only biological and environmental factors, but also access to infrastructure and services and assistance to women and babies by the health care system (França and Lanszy, 2008).

The relevance of birth outcomes in economics increases when investigating the determinants of future outcomes of individuals. Black, Devereux and Salvanes (2007) and Behrman and Rosenzweig (2004) found that LBW negatively affects educational attainment and future earnings of individuals. The mechanism assumed and tested by this literature is that fetal growth affects cognitive development in childhood, which in turn affects future productivity. Within this context, the literature suggests that economic and environmental conditions during pregnancy may have long-lasting effects on health outcomes and socioeconomic status and, therefore, might have effects on the labor market (Almond, 2006; Royes, 2009).

The climate and health area is relatively new in economics. When it comes to climate and birth outcomes, few authors have analyzed the association between these variables. Nevertheless, there is some evidence of a negative relation between the health of infants and maternal exposure to climate extremes (Deschênes, Greenstone and Guryan, 2009; Deschênes and Greenstone, 2007; Huynen et al., 2001; Curriero et al., 2002). These papers mainly analyze developed countries, lacking evidence for developing and underdeveloped countries.

This paper aims to understand the drivers of birth outcomes in Brazil with an emphasis on extreme weather events. In order to identify climate effects, we explore two different birth outcomes: neonatal mortality rate and low birthweight incidence. Both models use panel data but employ slightly different empirical strategies to identify weather effects.

This study contributes to the literature as it examines a wide and heterogeneous economy in transition like Brazil, using two different modeling strategies, as well as identifying policy instruments to deal with the potential harmful effects of changes in climate.

The structure of the paper is outlined as follows. Section 2 briefly describes the health economics literature that based the study. Section 3 summarizes the methodology used to assess the study of the climate impact on the neonatal mortality rate and applies it to our dataset. Section 4 discusses the determinants of low birthweight changes across Brazilian municipalities and estimates the role played by extreme weather events. Section 5 concludes the paper and discusses the climate change impacts, as well as the role played by education, access to public health assistance, water, and sanitation.

2. Literature Review

The theoretical framework of this study is based on the economic models of the family, which generates the approach of multivariate heath outcome functions as advocated by Becker and Lewis (1973). Grossman and Joyce (1988), Rosenzweig and Schultz (1982) and Corman and Grossman (1985) extended this model to identify the theoretical and empirical determinants of birth outcomes. The baseline idea behind the proposed procedure is that the parent's utility function depends on consumption, number of births and baby survival probability, which are endogenous variables except for consumption. The survival probability depends on the quality of medical care, nutrition and environmental issues during pregnancy. The health production function, in turn, depends on the efficiency of the mother in producing health, normally understood by the literature as the mother's ability or the role of her education (Behrman and Wolfe, 1987a, 1987b and 1989).

The parent's utility optimization[2] results in the demand function for survival, and the neonatal mortality rate is the complement of this function, which relates the survival probability to input prices, efficiency, income, tastes and fixed costs of a birth. In Brazil, health inputs in municipalities[3]— such as the availability of physicians who deliver prenatal and perinatal care, like those in the Family Health Care Program (or Primary Care Program), or the availability of obstetricians and nurses—lower the direct and indirect costs of obtaining medical care, which should increase the likelihood of a better birth outcome. Mothers' education is an important non-medical input in the production of healthy infants. Besides the inputs considered by the literature, here we test the climatic variables to explain birth outcomes, assuming that they represent a risk factor to the health of babies.[4]

The idea behind this analysis is summarized by the following equations:

$$s = 1 - d = g_1(n, b, x) \quad (1)$$
$$b = g_2(m, c, z, x) \quad (2)$$
$$m = g_3(p, z, y) \quad (3)$$
$$c = g_4(p, z, y) \quad (4)$$

[2] Maximizing the parents' utility function subject to the production and resource constraints generates the demand function for survival (Corman and Grossman, 1985).
[3] The local political unit in Brazil is the municipality, which is similar to a county, except there is a single mayor and municipal council. There are no unincorporated areas in Brazil.
[4] Deschênes and Greenstone (2007), Huynen et al. (2001), Godoy et al. (2008) and Maccini and Yang (2009).

in which s represents the survival function; d denotes the neonatal mortality rate and b measures the birthweight; p is a vector of variables related to the input prices (m and c); z denotes exogenous risks and productivity factors to improve infant's health; y represents the socioeconomic determinants to improve the birth outcomes; x are the exogenous variables related to climate influence during pregnancy; m are the medical and non-medical inputs; and c represents the use of contraceptive methods; and g_1 and g_2 represent the production function, while g_3 and g_4 are derived demand equations for the inputs considered.

Following Corman and Grossman (1985), the models to be estimated are the following production functions:[5]

$$s = 1 - d = g_5(p, z, y, x) \tag{5}$$

$$b = g_6(p, z, y, x) \tag{6}$$

The idea of this literature is to associate mortality and birth outcomes with the group of causes related to the parent's characteristics (mainly the mother's education and access to medical care), other socioeconomic and policy variables (income levels and distribution, sanitation conditions, age structure) and other medical input information.

The environmental variables considered are extreme events of temperature, precipitation and relative humidity in the period. To capture heterogeneities across Brazil, regional dummies and specific effects from panel data analysis are used.

Two models are proposed from different birth outcomes: one explaining the impact on neonatal mortality rate (equation (5)), and the other from the determinants of low birthweight (equation (6)). Sections 3 and 4 develop these ideas, respectively.

3. Extreme Events and Neonatal Mortality

3.1 Empirical Strategy and Dataset

We assume that extreme weather events are part of the environmental factors that affect infants' survival probability and consequently their mortality probability. Epidemiological studies have produced evidence of the relationship between exposure to extreme weather and birth outcomes (Murray et al., 2000; Lawlor, Leon and Smith, 2005).

[5] The reduced forms are the representation of the structural forms where the functional form for the endogenous variables (neonatal care inputs, birthweight, medical and non-medical inputs) are replaced into the production functions.

The dataset used for the neonatal mortality regression comprises annual information on the 27 Brazilian states from 2000 to 2011. State-level data are used to increase the time window of the panel data by using the National Household Survey (PNAD),[6] which provides the most complete data on socioeconomic information in the country and is statistically representative for the Brazilian states. It is relevant to mention that all the socioeconomic variables derived from the PNAD come from the responses of households in which a child was born in the year of analysis.

The mortality data include the number of infant deaths (0 to 27 days of life) out of total live births by Brazilian state from the Mortality Information System (SIM), supplied by the Datasus System of the Brazilian Ministry of Health. The Datasus System was also the source of all information regarding medical inputs such as number of nurses per inhabitant, participation in the Primary Care Program, and number of hospital beds per inhabitant.

Table 2 shows the summary statistics of the collected variables for the period between 2000 and 2011 by region of the country. Cities of the South region have lower neonatal mortality rates than the other regions, and show, on average, better socioeconomic indicators, such as education and infrastructure of households.

[6] This survey is conducted by the Brazilian Institute of Geography and Statistics (IBGE).

Table 2. Summary Statistics for Health and Socioeconomic Variables, 2001 to 2011, by Regions in Brazil

Variable	North			Northeast			Southeast			South			Midwest		
	Min	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Mortality rate per 100thd	814	1,288	2,141	879	1,314	3,419	791	1,124	4,309	756	979	1,337	789	1,130	1,737
% of illiterate mother	0.0	13.8	100.0	5.8	24.4	100.0	0.0	9.5	25.6	0.0	7.1	17.0	3.1	11.1	25.0
% of mother educ (<4years)	0.0	25.1	46.4	0.0	29.7	66.7	11.3	28.2	100.0	0.0	26.7	51.3	9.9	25.0	38.7
% of mother educ (4 to 8 years)	0.0	29.1	71.4	0.0	22.4	39.2	0.0	27.7	37.1	20.9	30.2	100.0	14.1	29.9	39.8
% of White	0.0	38.4	100.0	0.0	41.7	71.7	39.7	55.7	100.0	0.0	86.7	96.2	40.0	53.7	73.0
% of partic. Primary Care Prog.	41.3	56.0	93.0	53.1	69.0	84.4	8.9	28.0	58.2	19.6	47.4	65.0	10.0	48.7	62.6
Number beds per inhab.	1.36	2.02	3.98	1.93	2.61	4.81	2.00	2.74	4.56	2.48	2.96	4.06	2.01	2.81	5.43
Number nurses per inhab.	0.05	0.39	1.82	0.02	0.41	1.10	0.15	0.42	1.21	0.08	0.49	1.28	0.02	0.41	4.04
% hh with sewage	0.0	8.2	38.1	0.0	16.7	56.9	37.9	70.5	100.0	23.5	49.4	100.0	0.9	20.1	88.0
% hh with running water	0.0	79.7	100.0	30.6	72.4	94.7	79.3	97.4	100.0	87.6	97.5	100.0	70.4	95.9	100.0
% hh with waste collection	0.0	73.7	100.0	11.9	65.0	89.9	39.2	88.9	100.0	67.2	87.9	100.0	48.8	86.0	100.0
% urbanization	48.4	96.7	100.0	32.1	70.5	100.0	67.1	89.5	100.0	59.8	84.9	100.0	67.0	86.5	96.9

Note: hh = households; thd = thousand.

As for climate data, monthly information by weather station was collected from the National Meteorology Institute (INMET). The data included figures such as average, minimum and maximum temperature, average relative humidity and precipitation.[7]

Climate in Brazilian regions differs significantly. Tables 3 and 4 show the summary statistics for climate in Brazil. Temperatures are typically very high, especially in the northern region. On the other hand, the south of Brazil has lower temperatures (and occasional frosts and brief snowfalls during the winter). The northeastern region's cities are rainier, reaching approximately 3,000 mm of precipitation per year due to the proximity to the Amazon forest. The rainy season also lasts longer in this region, contrasting with the climate of the neighboring region, the Northeast, which has the highest temperatures and driest seasons in the country and savanna vegetation. When it comes to extreme events, heat stresses are more persistent. Winter and spring seem to be the most affected seasons, as Table 3 shows.

Table 3. Average Probability of Extreme Events Occurrence by Season and Region in Brazil (%)

Average occurence	North	Northeast	Southeast	South	Midwest
Summer					
Humidity – High	0.0	7.9	1.8	2.4	0.0
Humidity – Low	3.1	0.0	8.9	9.5	7.1
Flood stress	6.1	11.1	3.6	4.8	3.6
Rain stress	5.1	1.6	10.7	9.5	1.8
Heat stress	18.4	19.8	19.6	28.6	23.2
Cold stress	6.1	7.9	7.1	9.5	5.4
Winter					
Humidity – High	0.0	1.6	1.8	2.4	0.0
Humidity – Low	0.0	1.6	5.4	23.8	10.7
Flood stress	3.1	0.0	10.7	2.4	0.0
Rain stress	0.0	4.0	0.0	2.4	0.0
Heat stress	35.7	31.7	21.4	40.5	25.0
Cold stress	14.3	18.3	30.4	38.1	32.1

[7] Brazil's network of weather stations covers much of the coast. To transform the data from the weather stations into municipal data, the kriging method of spatial interpolation was used (Haas, 1990), which allows the interpolation of data with flexibility to specify the covariance between the outputs.

Table 4. Climate Description from INMET, Seasonal Long-Term Average (1980-2009), by Capital City of Brazilian State

Capital cities		Altitude (in meters)	Average Temperature (in ^{o}C)				Average Monthly Precipitaion (in mm)				Insolation hours - monthly average			
			DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
North	*Porto Velho*		25.5	24.9	23.9	25.6	262.	229.	85.4	147.	116.	130.	187.	149.
	Rio Branco		25.4	24.8	23.5	25.5	276.	195.	45.5	145.	107.	127.	186.	145.
	Manaus		26.3	26.3	26.7	27.4	264.	276.	86.6	107.	111.	120.	204.	162.
	Boa Vista		27.7	27.8	27.3	28.8	88.7	203.	274.	84.0	131.	130.	171.	185.
	Belém		26.2	26.2	26.4	26.9	203.	252.	100.	58.7	136.	144.	247.	226.
	Macapá		26.6	26.5	27.0	28.2	255.	312.	161.	41.7	157.	140.	233.	256.
	Palmas		25.6	25.7	25.1	26.7	269.	180.	7.95	136.	149.	192.	273.	188.
Norhteast	*São Luís*		26.6	26.3	26.4	27.3	207.	378.	113.	13.4	165.	143.	237.	246.
	Teresina		26.6	26.1	26.2	28.1	186.	231.	17.2	21.9	182.	195.	270.	255.
	Fortaleza		26.9	26.5	26.2	27.4	127.	312.	85.2	10.8	207.	177.	250.	270.
	Natal		26.8	26.4	25.0	26.5	81.9	208.	235.	23.9	234.	209.	223.	269.
	João		26.9	26.3	24.8	26.3	82.9	219.	262.	34.4	236.	203.	200.	255.
	Recife		26.6	26.0	24.3	25.7	98.9	229.	291.	44.5	228.	203.	190.	241.
	Maceió		25.7	25.1	23.1	24.7	71.8	193.	240.	50.5	225.	205.	194.	233.
	Aracaju		26.1	25.7	23.7	25.2	62.5	148.	143.	49.2	233.	211.	202.	242.
	Salvador		25.9	25.2	23.0	24.8	94.5	206.	172.	80.6	217.	195.	188.	217.
Midwest	*Campo*		24.2	22.1	19.0	22.4	210.	121.	50.0	136.	167.	181.	191.	165.
	Cuiabá		25.8	24.9	22.7	25.8	221.	112.	16.8	113.	153.	183.	206.	167.
	Goiânia		24.0	23.7	22.0	24.7	251.	136.	8.08	131.	154.	203.	243.	183.
	Brasília		21.8	21.1	19.4	22.1	226.	122.	10.8	125.	145.	204.	260.	178.
Southeast	*Belo*		23.2	21.6	18.6	21.9	274.	90.7	10.0	125.	167.	200.	229.	182.
	Vitória		25.4	23.9	20.9	23.1	149.	108.	52.1	121.	196.	201.	196.	165.
	Rio de		24.3	22.3	18.6	21.4	176.	134.	78.5	139.	185.	189.	188.	160.
	São Paulo		22.6	20.2	16.6	19.6	240.	119.	42.5	121.	152.	167.	167.	149.
South	*Curitiba*		21.2	18.0	14.0	17.2	172.	114.	72.3	147.	162.	162.	161.	141.
	Florianópol		23.4	20.7	15.7	19.5	188.	137.	61.6	164.	179.	184.	164.	150.
	Porto		23.5	19.9	14.3	18.9	121.	106.	119.	146.	208.	183.	146.	169.

Based on the available data and on the theoretical framework described at Section 2, the final equation to be estimated is:

$$E(d_{jt}/p,z,y,x,\alpha) = 1 - g_5\left(p_{jt}, z_{jt}, y_{jt}, x_{jSt}, \alpha_j\right) \tag{7}$$

In other terms:

$$d_{jt} = \exp[\theta_1^{H,L} T_{jtS}^{H,L} + \theta_2^{H,L} R_{jtS}^{H,L} + \mathbf{y}_{jt}\gamma_y + \mathbf{z}_{jt}\gamma_z + \mathbf{p}_{jt}\gamma_p + \alpha_j + \alpha_t + \xi_{1jt}] \tag{8}$$

in which *j* and *t* are the regional (states) and time (year) units, respectively; *S* represents the season of the year (summer, fall, winter and spring); *d* denotes the neonatal mortality rate (NMR), calculated by the ratio of deaths recorded among newborns from 0 to 27 days of life and total of live births; ***p*** is a vector of relative variables related to medical and non-medical inputs (number of hospital beds per infant, number of nurses per inhabitant, participation in the Primary Care Program[8]); ***z*** denotes exogenous risks and productivity factors to improve infant health (this study considers mother's education as the main productivity factor); ***y*** represents the socioeconomic determinants of improved birth outcomes (access to running water, sewage system and waste collection); *x* is the vector of environmental exogenous variables representing the weather index for extreme events related to temperature and rainfall *(T,R*) during pregnancy; α_j is municipality group-specific effects (controlling for, among other factors, level of urbanization, the ratio of abortion and use of contraceptive methods among states/municipalities); α_t are specific effects for the years of the sample; g_5 represents the production function, considered as exponential; and ξ_{1jt} is the stochastic error term.

The climate variables, $(T_{jtS}^{H,L}, R_{jtS}^{H,L})$, for each year are de-meaned by the long-term climate data (30-year average: μ_{climate}) and divided by the long-term standard deviation, calculated from the former 30-year climate (σ_{climate}), in order to standardize the climate information. In this formulation, observations higher or lower than two standard deviations from the historical average are considered extreme events. A historical moving average, based on the 30-year climate at each date, was also calculated and tested in the model to control for the increase in long-term average caused by climate change, but the results did not change significantly.

[8] In terms of public policy for the health of the newborns, the Primary Care Program seems to be more relevant than Bolsa Familia. Bolsa Familia could be a better policy to analyze the health of older children, as its conditionals include education of the children of the family.

Therefore, the long-term climate conditions considered the fixed time window from 1981 to 2010.[9]

3.2 Results

Equation (8) was estimated with panel data and bootstrapped standard errors. The software used was Stata 12 SE. The main results are reported in Table 5.

When it comes to the climate variables, joint tests show they are relevant to explain neonatal mortality rate (p-value = 0.003, for the regional specifications, and p-value = 0.065, for the Brazilian equation), especially for the Northeast and Midwest regions. Negative and statistically significant effects of climate on mortality are identified mainly for rain stress (rain above the average) in Brazil, and in the Northeast region during summer. Summer is a very rainy season in Brazil, and it accounts for many harmful events during this season. High temperatures during summer can also have a negative effect on the mortality of babies during summer in the Northeast region and during fall in the Midwest region.

[9] It was not possible to consider a threshold for extreme events as this paper uses seasonally aggregated data for weather.

Table 5. Regression Output, Neonatal Mortality Rate Equation, Brazil and Regional Specifications

Dependent variable: ln(d)	(1) RE - Regional	(2) RE - Regional	(3) RE – Regional	(4) FE - Regional		(5) RE - Brazil
Rain stress - Summer (North)	0.0227	0.0804	0.0642	0.0737	High humidity - Summer	-0.0181
	(0.0768)	(0.0926)	(0.0771)	(0.0856)		(0.0544)
Rain stress - Winter (North)	0.462***				Rain stress - Summer	0.0939*
	(0.0106)					(0.0512)
Rain stress - Summer (Northeast)	0.0519*	0.0980	0.0896	0.0809*	Heat stress - Summer	0.0759
	(0.0278)	(0.0643)	(0.0660)	(0.0484)		(0.0747)
Cold stress - Summer (Northeast)	-0.0915	0.0943*	0.124***	0.137***	Drought stress - Winter	0.0279
	(0.0632)	(0.0514)	(0.0441)	(0.0207)		(0.0956)
Heat stress - Summer (Northeast)	-0.121*	0.132***	0.169***	0.172***	Cold stress – Winter	0.0972
	(0.0662)	(0.0421)	(0.0566)	(0.0255)		(0.0605)
Drought stress - Winter (Northeast)	0.0196	0.145***	0.105**	0.0814***	High humidity - Spring	-0.0492
	(0.146)	(0.0384)	(0.0414)	(0.0204)		(0.0824)
Drought stress - Spring (Northeast)	0.139***	0.163	0.146	0.145**	Rain stress – Spring	-0.0281
	(0.0345)	(0.101)	(0.105)	(0.0675)		(0.0348)
Drought stress - Summer (South)	-0.0177	0.0475	0.0201	0.00574		
	(0.0311)	(0.0349)	(0.0359)	(0.0248)		
Rain stress - Winter (South)	-0.0503	-0.0347	0.0173	0.0471**		
	(0.102)	(0.0678)	(0.0512)	(0.0212)		
Drought stress - Winter (South)	0.108*	-0.00633	0.0321	0.0436		
	(0.0560)	(0.0772)	(0.0762)	(0.0487)		
Rain stress - Spring (South)	-0.0127	-0.0732*	-0.0690	-0.0639**		
	(0.0774)	(0.0417)	(0.0511)	(0.0260)		
Heat stress - Fall (Midwest)	-0.0804***	0.232***	0.200***	0.169***		
	(0.0167)	(0.0459)	(0.0533)	(0.0325)		
Mother education		yes	Yes	yes		yes
Socioeconomic variables		yes	Yes	yes		yes
Medical infrastructure		yes	Yes	yes		yes
Sanitation infrastructure				yes		yes
Observations	384	189	189	189	Observations	189
R-squared (within)	0.053	0.46	0.56	0.57	R-squared (within)	0.53
Number of states	27	27	27	27	Number of states	27

Note: Bootstrapped standard errors in parentheses (1000 replications); *** p<0.01, ** p<0.05, * p<0.10; RE: Random Effects; FE: Fixed Effects.

The squared correlation between the predictions and the dependent variables are reported below, indicating a good fit of most of the models.

Table 6. Squared Correlation between the Neonatal Mortality Rate and its Prediction, Brazil and Regional Specifications

Models	RE/FE	Climate variables	Squared correlation of NMR and prediction
(1)	RE	Regional	0.3626
(2)	RE	Regional	0.8541
(3)	RE	Regional	0.8752
(4)	FE	Regional	0.8795
(5)	RE	National	0.8671

Despite the statistical relevance of climate variables to explain the neonatal mortality rate in Brazil, the evidence found using mortality data is not very strong mainly due to the use of aggregate data and limited range of data, but it seems to be satisfactory to indicate a potential negative effect of extreme rainfall events on the health of newborns in Brazil. Temperature-related impacts on neonatal mortality are also not very strong in the literature for the United States[10] (Scheers-Masters, Schootman and Thach, 2004), but epidemiological evidence indicates an effect of extreme temperatures on birth outcomes (Strand, Barnett and Tong, 2011).

4. Extreme Events and Low Birthweight

4.1 Empirical Strategy

The low birthweight equation is estimated following the empirical strategy of Deschênes and Greenstone (2007) and Deschênes, Greenstone and Guryan (2009), but limited by the data availability problems of Brazilian datasets.

Birthweight information was collected by month from 2005 for families that are part of Brazil’s Primary Care Program (PCP); this information is available from the Information System for Primary Care (SIAB), Datasus System. Through home visits, community health agents register families, identify their housing and sanitation situation and monitor families’ health status. The limitation of this dataset is related to the number of families covered by the Primary Care sample. Socioeconomic variables are also collected by the same dataset, representing the municipality’s average conditions of the families from the sample. The table below compares the main information from SIAB sample data and Brazilian data (PNAD and SINASC).

[10] Stronger evidence is found between humidity stressors and mortality of newborns.

Table 7. Variables Description and Statistics: SIAB, SINASC and PNAD Samples

Information		Year	Total Brazil (PNAD and SINASC)		PCP - Brazil (SIAB Sample)	
			Total	%	Total	%
Number of families		2012	**65,894,191**	**100**	**34,624,027**	**100**
	Individuals per family - average		2.99		3.48	
Number of Individuals		2012	**196,877,328**	**100**	**120,572,488**	**100**
Region	North		16,729,979	8.5	11,209,090	9.3
	Northeast		54,642,945	27.8	45,713,700	37.9
	Southeast		82,686,676	42.0	38,703,617	32.1
	South		28,052,511	14.2	16,497,325	13.7
	Midwest		14,765,217	7.5	8,448,756	7.0
Area	Rural	2012	29,861,912	15.2	25,509,106	21.2
	Urban		167,015,416	84.8	95,063,382	78.8
Gender	Male	2012	95,812,480	48.7	58,684,958	48.7
	Female		101,064,848	51.3	61,886,933	51.3
Age	Children (0 to 14 years)	2012	44,989,636	22.9	26,042,363	21.6
	Adults (15 to 59 years)		127,032,071	64.5	79,756,749	66.1
	Elderly (over 60 years)		24,855,621	12.6	14,772,779	12.3
	Number of illiterates (>15 years)	2012	13,162,983	8.7	10,356,865	11.0
Live births		2011	**2,913,160**	**100**	**1,190,538**	**100**
Region	North		313,029	10.7	123,038	10.3
	Northeast		851,181	29.2	529,462	44.5
	Southeast		1,144,213	39.3	309,061	26.0
	South		378,000	13.0	152,502	12.8
	Midwest		226,737	7.8	76,475	6.4
Live births (weighted)		2011	**2,909,791**	**100**	**1,166,709**	**100**
	Low birthweight (<2.5 kg)		248,217	8.5	118,124	10.1
	Normal weight at birth (>2.5 kg)		2,661,574	91.5	1,048,585	89.9
Total of families		2012	**65,894,191**	**100**	**34,624,027**	**100**
	Electricity		65,575,925	99.5	33,000,444	95.3
	Sewage		37,599,332	57.1	14,887,423	43.0
	Running water		55,587,049	84.4	26,990,403	78.0
Number of individuals		2012	**196,877,328**	**100**	**120,572,488**	**100**
	Lack of health care[1]	2008	7,284,461	3.7	5,184,617	4.3

[1] Unattended individuals who needed health care (% based on PNAD 2008 and number estimated from 2012 data).

In 2012, the SIAB sample represented 52.6 percent of total families in Brazil, mainly concentrated in rural areas, covering 85.4 percent of total rural families. From the table above, it is possible to notice that the sample is more representative for the northern and northeastern regions. The data better represents the most vulnerable groups of people in the country, as is observed by comparing the infrastructure and socio-demographic variables differences among the samples.

Using this dataset, the framework presented at Section 2 and the paper of Deschênes, Greenstone and Guryan (2009), the equation to be estimated is:

$$E(b_{cgi}/p,z,y,x,\alpha) = g_6\left(p_{cgi}, z_{cgi}, y_{cgi}, x_{cgi}, \alpha_{cg}, \alpha_{tg}, d_{cgi}\right) \tag{9}$$

In other terms:

$$b_{cgi} = \exp[\,\theta_g^{TR1} C_{cgi}^{TR1} + \theta_g^{TR2} C_{cgi}^{TR2} + \theta_g^{TR3} C_{cgi}^{TR3} + \mathbf{y}_{cgi}\beta_y + \mathbf{z}_{cgi}\beta_z + \mathbf{p}_{cgi}\beta_p + \alpha_{cg} + \alpha_{tg} + \boldsymbol{d}_i\alpha_d + \xi_{2cgi}] \tag{10}$$

in which *t, i* represent the year (2005 to 2012) and month, respectively;[11] *c* represents the 5,564 municipalities; *g* is the demographic group (*g* = rural or urban households); *b* denotes the cases of LBW (weight at birth lower than 2.5 kg); ***p*** is a vector of relative variables related to medical and non-medical inputs (number of obstetricians per inhabitant, dummy for hospital in the municipality); ***z*** denotes exogenous risks and productivity factors to improve infants' health (pregnant women with prenatal care, which is a proxy for mother's education); ***y*** represents the socioeconomic determinants to improve birth outcomes (type of water supply; waste disposal; connection to sewage system); *x* is the vector of exogenous variables ($C_{cgi}^{TR1}, C_{cgi}^{TR2}, C_{cgi}^{TR3}$), representing the weather index for extreme events during each of the three trimesters of pregnancy (explained below); *d* is a dummy variable for the "month of the year" of birth (conception is defined as nine months before the birthday month[12]), which controls for the potential monthly seasonality; α_{cg} are municipality-specific effects (controlling for, among other factors, the use of contraceptive methods among cities); α_{tg} are specific effects for the years of

[11] The sample covers all the months from 2005 to 2012 (96 months).

[12] The dataset does not allow the identification of the date of conception to control for premature death from climate problems. This may cause an overestimation of the effect of the extreme weather events on the last trimester of pregnancy. However, the Brazilian national sample suggests that a premature birth occurs in 6-10 percent of cases overall. Due to the low incidence of premature death and the many causes of its incidence, the bias for not considering this information can be reduced.

the sample; g_6 represents the production function, which is considered an exponential function; and ξ_{2cgi} is the stochastic error term.

The municipality-specific effects also account for cross-sectional variation in weather and birthweight, as well as the monthly seasonal dummies are included to capture the effect of any secular difference in within-year birth outcomes that is independent of weather exposure.

The climate variables of interest, $C_{cgi}^{TR1}, C_{cgi}^{TR2}$ and C_{cgi}^{TR3}, are the measures of the existence of extreme events related to relative humidity, temperature and precipitation during each trimester of the gestational period (3rd trimester: 7th to 9th month of the pregnancy; 2nd trimester: 4th to 6th month of the pregnancy; and 1st trimester: 1st to 3rd month of the pregnancy).

The same procedure explained at Section 3 is considered to define "extreme weather events": a weather observation above or below 2 standard deviations from the historical mean (and moving-average mean). After conditioning on municipality-year-demographic group effects, the associated parameters are identified from municipality-specific deviations in weather from the municipal averages, after controlling for municipality-specific annual shocks.

Table 8 shows the description of such measures of extreme events calculated by trimester. The description shows some regularity amongst the trimesters, except for the heat stresses, which seem to be more relevant for the last trimesters of pregnancy, on average.

Table 8. Average Incidence of Extreme Weather Events by Trimester (percentage)

Variable	**Mean (%)**
High humidity - 3rd trimester (TR3)	1.79
High humidity - 2nd trimester (TR2)	1.80
High humidity - 1st trimester (TR1)	1.82
Low humidity - 3rd trimester (TR3)	6.18
Low humidity - 2nd trimester (TR2)	6.12
Low humidity - 1st trimester (TR1)	6.10
Cold stress - 3rd trimester (TR3)	0.70
Cold stress - 2nd trimester (TR2)	0.70
Cold stress - 1st trimester (TR1)	0.73
Heat stress - 3rd trimester (TR3)	12.21
Heat stress - 2nd trimester (TR2)	11.07
Heat stress - 1st trimester (TR1)	9.89

Due to the unpredictability of weather fluctuations, it is possible to assume that this variation is orthogonal to unobserved determinants of birthweight.

The dependent variable of the model, number of low birthweight newborns (birthweight below 2.5 kg) in the municipality, has a nonnegative and discrete data generating process. Therefore, its distribution places probability mass at nonnegative integer values only. For this reason, equation (10) is estimated considering the negative binomial distribution. The negative binomial specification is a count data model that accounts for overdispersion from the presence of unobserved heterogeneity, mainly from the excess of zeroes (Cameron and Trivedi, 2009). The logarithm of total live births was included with a constraint coefficient (equal to one), considered as an offset variable to obtain the low birthweight rate.

4.2 Results

The LBW regression was estimated by demographic group of households (*g*): rural; and urban. The main results are reported in Tables 9 and 10. All the models rejected overdispersion, supporting the estimation of the negative binomial.

For rural households, there is evidence of the harmful effects of cold stress during the third trimester of pregnancy, as well as extreme humidity levels—both high and low. When it comes to heat stress, the coefficient was statistically significant only for the second trimester of pregnancy. Deschênes and Greenstone (2009) also found significant results of the effect of extreme hot days on LBW mainly during the second and third trimesters, and the signal of the effects are the same as the one found in this study, which means a possible negative effect of extreme hot temperatures on the incidence of low birthweight for Brazilian rural households. For urban households, similar results are observed, but the magnitude was a bit higher than for the rural households. The results are not directly comparable, as Deschênes and Greenstone estimate the specific effect of the observation of temperature bins on the birthweight of the babies.

Table 9. Extreme Weather Impacts on Low Birthweight: Rural Households

Dependent variable: Cases of low birthweight	(1)	(2)	(3)	(4)	(5)
High humidity - TR3	-0.01265	0.0216	0.0501*	0.0172	0.0235
	(0.0153)	(0.0138)	(0.0271)	(0.0250)	(0.0281)
High humidity - TR2	0.00711	0.0323**	0.0585**	0.0297	0.0338
	(0.0133)	(0.0138)	(0.0258)	(0.0237)	(0.0283)
High humidity - TR1	0.0197	0.0530***	0.0289	-0.00915	-0.00693
	(0.0136)	(0.0137)	(0.0261)	(0.0242)	(0.0268)
Low humidity - TR3	0.0516***	0.00241	0.00848	0.0207	0.0202
	(0.0104)	(0.0106)	(0.0171)	(0.0159)	(0.0179)
Low humidity - TR2	0.0324***	-0.0111	0.00160	0.0132	0.0138
	(0.0106)	(0.0103)	(0.0172)	(0.0160)	(0.0189)
Low humidity - TR1	0.0443***	0.00668	0.0291*	0.0306**	0.0306*
	(0.0104)	(0.0102)	(0.0163)	(0.0152)	(0.0191)
Cold stress - TR3	0.2107***	0.0213*	0.0397**	0.00796	0.0191
	(0.0118)	(0.0117)	(0.0176)	(0.0176)	(0.0121)
Cold stress - TR2	0.131***	0.0116	-0.00185	-0.0181	-0.0141
	(0.0123)	(0.0118)	(0.0180)	(0.0174)	(0.0199)
Cold stress - TR1	0.205***	0.0194	-0.0130	-0.0495**	-0.0338
	(0.0110)	(0.0126)	(0.0193)	(0.0195)	(0.0225)
Heat stress - TR3	-0.0087	0.00510	0.0202*	0.0100	0.0110
	(0.00556)	(0.00784)	(0.0114)	(0.0107)	(0.0107)
Heat stress - TR2	0.0248***	0.0234***	0.0241**	0.0199*	0.0207**
	(0.0083)	(0.00880)	(0.0113)	(0.0104)	(0.0105)
Heat stress - TR1	0.0094	0.0172**	0.00165	-0.00403	-0.00341
	(0.0084)	(0.00840)	(0.0111)	(0.0103)	(0.0108)
Sanitation variables			yes	yes	Yes
Medical variables			yes	yes	Yes
Dummy for states		yes	yes		Yes
Dummy for year			yes	yes	Yes
Dummy for month			yes	yes	Yes
Random / Fixed effects				Fixed	Random
Observations	**490,755**	**490,755**	**213,647**	**212,736**	**213,647**
Municipalities (panel)				**3,610**	**3,847**

Note: Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

Table 10. Extreme Weather Impacts on Low Birthweight, Urban Households

Dependent variable: Cases of low birthweight	(1)	(2)	(3)	(4)	(5)
High humidity - TR3	-0.00265	0.0321***	0.0286*	0.0154	0.0187
	(0.0111)	(0.009)	(0.017)	(0.0141)	(0.0159)
High humidity - TR2	-0.0081	0.0213**	0.0151	0.00410	0.00729
	(0.0103)	(0.0095)	(0.0158)	(0.0135)	(0.0134)
High humidity - TR1	0.0035	0.0381***	0.0257	0.00735	0.00854
	(0.0102)	(0.0116)	(0.0158)	(0.0136)	(0.0160)
Low humidity - TR3	0.0419***	-0.00783	-0.00626	0.0100	0.00970
	(0.0071)	(0.0070)	(0.0099)	(0.0084)	(0.0101)
Low humidity - TR2	0.0491***	0.00239	0.00065	0.0159*	0.0149*
	(0.006)	(0.0067)	(0.00966)	(0.0083)	(0.0088)
Low humidity - TR1	0.0547***	-0.00234	-0.00779	-0.00148	-0.00313
	(0.006)	(0.00624)	(0.0103)	(0.0079)	(0.0095)
Cold stress - TR3	0.0294*	0.0379**	-0.270**	-0.0952	-0.0931
	(0.0166)	(0.0155)	(0.137)	(0.133)	(0.159)
Cold stress - TR2	-0.05878	0.00304	0.0871	0.241**	0.258**
	(0.0166)	(0.0163)	(0.118)	(0.110)	(0.112)
Cold stress - TR1	-0.079	-0.00221	-0.159	0.0224	0.0171
	(0.0173)	(0.0165)	(0.106)	(0.122)	(0.137)
Heat stress - TR3	0.0192***	-0.013**	0.00076	-0.015**	-0.0140
	(0.0055)	(0.0062)	(0.0077)	(0.0069)	(0.0092)
Heat stress - TR2	0.021***	0.0138**	0.025***	0.013**	0.0143**
	(0.0065)	(0.0066)	(0.0079)	(0.0066)	(0.00660)
Heat stress - TR1	0.0050	-3.31e-05	0.00125	-0.00689	-0.00454
	(0.0061)	(0.00630)	(0.0079)	(0.0066)	(0.0079)
Sanitation variables			yes	yes	yes
Medical variables			yes	yes	yes
Dummy for states		yes	yes		
Dummy for year			yes	yes	yes
Dummy for month			yes	yes	yes
Random / Fixed effects				Fixed	Random
Observations	**693,107**	**693,107**	**329,109**	**328,688**	**329,109**
Number of municipalities (panel)				**5,048**	**5,093**

Note: Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10.

In summary, the results are not conclusive, but they suggest that exposure to some of the extreme weather events during pregnancy and early days might lead to lower birthweight or higher mortality rate of the babies in Brazil. In order to best understand the magnitude of such impacts, in Section 5 climate change forecasts are used to calculate and predict the potential effect of climate change on both of the birth outcomes.

5. Discussion

Sections 3 and 4 shows some evidences of significant effect of climate on the birth outcomes in Brazil. This evidence is in accordance with the results observed for developed countries. This section discusses the extensions of the results in terms of climate change and adaptation measures.

5.1 Climate Change Projections

The climate change forecast used were generated from the data set boundaries of the global model (HadCM3), from the Met Office-Hadley Centre of the United Kingdom, A1B emission scenario for the entire area of South America considering 2041-2070 as future climate (the three scenarios considered indicate the level of human activity that influence the climate: Low; Middle—Midi; and High). The variables used as the average of the expected extreme weather events were calculated similarly as the independent variables of the models were calculated. Considering the average scenario (Midi), the climate change expected effects on neonatal mortality are reported in Table 11[13] and the effects on low birthweight are shown in Table 12.

Table 11. Climate Change Estimated Effect on Neonatal Mortality, 2041-2070, by region, Average Scenario

Region	NMR (%)		NMR per 100,000 alive newborns		Difference in incidence	Difference in cases
	Current	Projected	Current	Projected		
North	1.191	1.187	11.9167	11.8714	-0.0454	**-15**
Northeast	1.222	1.236	12.2205	12.3613	0.1408	**125**
Southeast	0.961	0.972	9.6103	9.7217	0.1114	**126**
South	0.872	0.883	8.7249	8.8319	0.1070	**40**
Midwest	1.001	1.006	10.0095	10.0620	0.0525	**29**
Brazil (average)	**1.057**	**1.067**	**10.5716**	**10.6697**	**0.0981**	**305**

[13] All three scenarios converged to the same predictions, thus the average scenario is reported.

According to the forecasts, the most affected areas will be the Northeast and Southeast of Brazil, as most of the statistically significant extreme weather events' effects found were from these areas of the country. The Northeast region normally faces many weather problems during the drier seasons, lack of rainfall and extreme hot temperatures; as for the southern and southeastern part of the country, rain is also an issue when it comes to the drier and wetter seasons. The climate change evidences suggest an increase in incidence of neonatal mortality per live births, which may cause the additional death of 305 newborns per year, considering the number of live births in Brazil in 2010.

Next table shows the climate change impacts forecasted using the low birthweight equation, estimated using a sample that covers about 52 percent of Brazilian households, mainly the poorer ones.

Table 12. Climate Change Estimated Effect on Low Birthweight (LB) Indicators, 2041-2070

Forecast Scenario	LBR in p.p. (%)	LB per 100k alive babies	LB current average cases (%)	Total increase/decrease in LB cases per year
Rural households				
Scenario High	0.416	4.16	4.77	1,252
Scenario Midi	0.415	4.15	4.76	1,249
Scenario Low	0.300	3.00	3.44	833
Urban households				
Scenario High	0.202	2.02	2.23	1,837
Scenario Midi	0.211	2.11	2.33	1,922
Scenario Low	-0.027	-0.27	-0.30	(230)
Rural + Urban households				
Scenario High	**0.256**	**2.56**	**2.86**	**3,088**
Scenario Midi	**0.263**	**2.63**	**2.94**	**3,171**
Scenario Low	**0.056**	**0.56**	**0.63**	**603**

From the table above, it is possible to infer that expected climate change might increase the number of babies with low birthweight from 603 to 3,171, depending on the scenario considered. Rural households are expected to suffer more from climate effects than urban households. The forecasts were also performed from each region and by month, in order to capture impacts' regional sensitivity and seasonality, respectively.

Figure 1. Increase in LBR, by Month and Scenario, 2041-2070 (percent change)

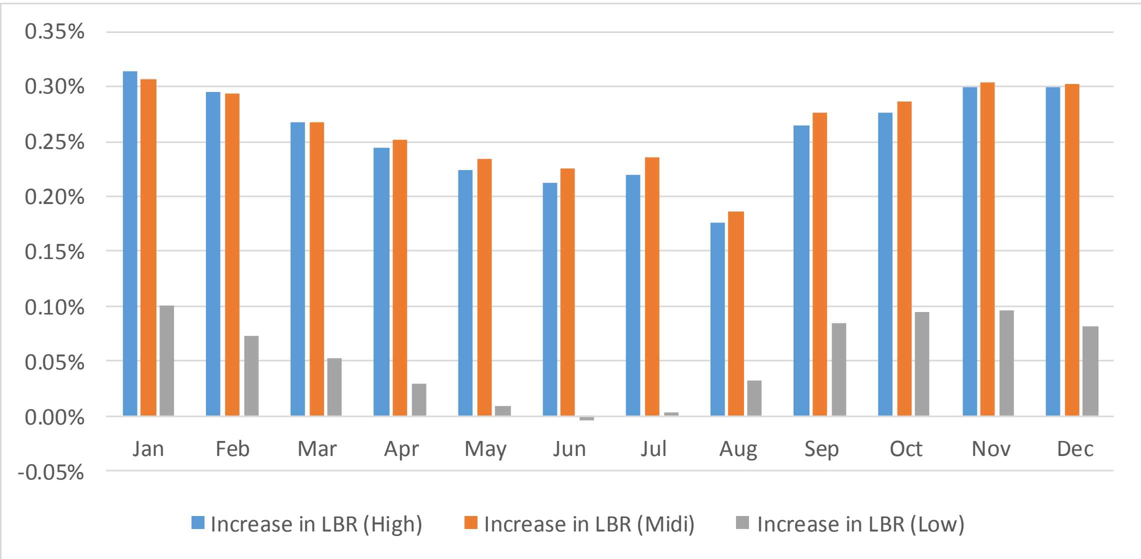

Table 13. Climate Change Estimated Effect on the Proportion of Low Birthweight Babies by Region, 2041-2070 (percent change)

Region	Scenario High	Scenario Midi	Scenario Low
North	0.63%	0.63%	0.58%
Northeast	0.16%	0.16%	0.03%
Southeast	0.24%	0.25%	-0.03%
South	0.30%	0.33%	-0.05%
Midwest	0.24%	0.25%	-0.14%
Brazil	**0.26%**	**0.26%**	**0.06%**

From Figure 1, it is possible to conclude that the vulnerable group of the newborns will be more affected by the increase of extreme events from September to February/March, when the highest temperatures are observed in Brazil. When it comes to the vulnerable regions, Table 13 shows that the North and South regions are more affected in terms of birthweight.

5.2 Adaptation Measures

To examine the public policy's role in minimizing the potential harmful effects of climate in Brazil, the effects of the inputs considered in the health production functions can be used. The following tables report the estimated effects for the potential adaptation variables for all the estimated equations.

Table 14. Effects of Potential Adaptation Measures: Neonatal Mortality Equation

Dependent variable: ln(d)	**(2)** **RE** **Regional**	**(3)** **RE** **Regional**	**(4)** **FE** **Regional**	**(5)** **RE** **Brazil**
Climate controls	yes	yes	Yes	yes
Mother's education: 0 years	0.457**	0.337	0.273*	0.327
	(0.194)	(0.357)	(0.160)	(0.365)
Mother's education: <4 years	0.767***	0.505**	0.390*	0.499**
	(0.246)	(0.232)	(0.203)	(0.223)
Mother's education: 4 to 8 years	0.322	0.132	0.0663	0.183
	(0.228)	(0.199)	(0.242)	(0.214)
% of hh with sewage system		-0.180	-0.228	-0.246*
		(0.136)	(0.162)	(0.149)
% of hh with running water		-0.118	-0.112	-0.213
		(0.271)	(0.186)	(0.318)
% of hh with trash collection		-0.469*	-0.606**	-0.437
		(0.277)	(0.251)	(0.333)
% of urban hh		0.596**	0.733***	0.615**
		(0.286)	(0.200)	(0.263)
% of white families	-0.248*	-0.121	0.0234	-0.0357
	(0.131)	(0.132)	(0.136)	(0.175)
% of families in Family Health Prog.	0.106	-0.0874	-0.198	-0.159
	(0.101)	(0.123)	(0.185)	(0.131)
Hospital beds per inhabitant	-0.0385	-0.0527	-0.0435	-0.0422
	(0.0389)	(0.0431)	(0.0370)	(0.0436)
Nurses per inhabitant	-0.0724	-0.0642	-0.0638	-0.0607
	(0.0586)	(0.0557)	(0.0525)	(0.0620)

Note: Bootstrapped standard errors in parentheses (1,000 replications); *** p<0.01, ** p<0.05, * p<0.1.
hh: household.

For the neonatal mortality rate, the education of the mother seems to be an important reducer of mortality. The base dummy considers mother's education higher than eight years. The worst education level for mortality seems to be the group of mothers who had not completed elementary school, a result that is consistent in all specifications. In terms of local infrastructure, sewage system had statistically significant coefficients, suggesting that these are the most important ways of reducing mortality. When it comes to medical care access, the number of nurses per inhabitant seems to be the most important medical input for the population studied. Nurses have an important role in increasing the knowledge of poor families, in terms of hygiene and primary care. The coefficients were statistically significant for robust estimations, but the significance vanished when the bootstrapped standard errors were estimated.

Table 15. Effects of Potential Adaptation Measures, Low Birthweight Equation

Dependent variable: Cases of low birthweight	**Urban Households**			**Rural Households**		
	(3)	**(4)**	**(5)**	**(3)**	**(4)**	**(5)**
Climate variables	yes	yes	Yes	yes	yes	yes
hh with sewage system	-0.0150	0.00358	-0.0213	-0.0572**	-0.0845	-0.0778*
	(0.0188)	(0.0439)	(0.048)	(0.0258)	(0.0573)	(0.0469)
hh with running water	0.00499	0.0306	0.00119	-0.0131	0.00585	-0.0163
	(0.0151)	(0.0327)	(0.0352)	(0.0176)	(0.0452)	(0.0434)
hh with collected waste	0.0576***	-0.0952***	-0.0102	0.0809***	0.00715	0.0523
	(0.0189)	(0.0353)	(0.0338)	(0.0207)	(0.0451)	(0.0455)
pregnant women with prenatal care	-0.150***	-0.0468**	-0.0762**	-0.0858***	-0.100***	-0.110***
	(0.0178)	(0.0237)	(0.0366)	(0.0197)	(0.0283)	(0.0377)
Dummy for presence of hospital	-0.0306***	-0.0813***	-0.0359***	-0.0191***	0.0255	-0.00255
	(0.00566)	(0.0166)	(0.01277)	(0.00689)	(0.0208)	(0.0162)
Number of obstetrician per inhabit.	0.207***	-0.241***	-0.153*	0.215***	0.106	0.182*
	(0.0287)	(0.0596)	(0.0825)	(0.0792)	(0.128)	(0.135)

Bootstrapped standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

When it comes to the low birthweight equation, similar results are found. For rural households, sewage system remains the main reducer of birth health problems. Prenatal care seems to be the most important instrument for detecting future problems in pregnancy, a result that is consistent with the literature for Brazil (Comparini, 2013). For both urban and rural households, the presence of hospitals in the municipality is also an important input to reduce the number of babies with low weight at birth.

5.3 Final Remarks

Evidence of harmful effects of extreme weather events on birth outcomes could be detected from the estimations. Although this evidence is not very strong, mainly due to the use of aggregate data, it seems to indicate a potential negative effect of extreme weather events on birth outcomes in Brazil.

This paper was also able to estimate other determinants of the birth outcomes and, therefore, identify instruments that have the potential to smooth climate change effects. Mother's education, access to sewage and trash collection, and access to medical assistance are among these instruments. These findings allow us to make recommendations to policymakers and reinforce the Brazilian literature of health outcomes, suggesting that improvements in education and public health infrastructure seem potentially important in explaining a large part of the observed changes in health outcomes (Soares, 2007).

The government's influence, in terms of public policy, is mainly given by the universalization of running water and sewage collection (both urban infrastructure problems controlled by the local government), by educational measures (prenatal care, etc.), and by assuring proper health assistance to pregnant women and newborns.

This study contributes to the literature on health and climate as it brings the discussion to a developing country context. It also calculates the climate change effects on two measures of newborns' health. It is possible to understand the effects of changes in climate on both mortality and health outcomes, which are relevant indicators for the future achievements of individuals, as highlighted by Black, Devereux and Salvanes (2007) and Behrman and Rosenzweig (2004).

For future research, we intend to use disaggregated data, not currently available for research, from the SIAB dataset, as well as further determine level of mother's education that is relevant to harmful birth outcomes. Another possible extension is the calculation of a compensating differentials approach to give monetary values to the effects calculated, such as undertaken in Soares (2007).

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