The Perils of Climate Change: In Utero Exposure to Temperature Variability and Birth Outcomes in the Andean Region

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Abstract

The discussion on the effects of climate change on human activity has primarily focused on how increasing temperature levels can impair human health. However, less attention has been paid to the effect of increased climate variability on health. We investigate how *in utero* exposure to temperature variability, measured as the fluctuations relative to the historical local temperature mean, affects birth outcomes in the Andean region. Our results suggest that exposure to a temperate one standard deviation relative to the municipality's long-term temperature mean during pregnancy reduces birth weight by 20 grams and increases the probability a child is born with low birth weight by 10 percent. We also explore potential channels driving our results and find some evidence that increased temperature variability can lead to a decrease in health care and increased food insecurity during pregnancy.

Key Words: Climate Change, Temperature Variability, Birth Weight, Health
JEL Codes: I10, I15, J13, Q54

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1. Introduction

The debate concerning the effects of climate change on human activity has intensified in recent years. It is well recognized that climate change has increased global temperatures over the past few decades, but only recently have meteorologists explored whether temperature variability - fluctuations over the long-term local temperature mean - has also increased over time (Thompson et al. 2013; Thornton et al. 2014; Wang and Dillon 2014). These enquiries, though, are in their very early stages and an accurate picture of how temperature variability can affect human activity remains unclear.

Despite this lack of research, institutions all over the world are becoming more interested in the potential effects of temperature variability on health. A particular awareness of this topic has been raised for developing countries where the use of adaptation technologies, such as air conditioning or heating, is not widespread. For instance, the European Research Framework Programme states that exploring these effects "[…] is particularly important for low income countries, where the influence of climate variability on health is widely recognized and where economic development is severely affected by disease in humans and animals."

Aside from this discussion, there is growing evidence that climate change is contributing to the prevalence of disease, especially among vulnerable populations. A recent report from the World Health Organization (WHO) posits that "(…) health and other impacts [of climate change] may fall disproportionately on women, children, people with disabilities, and elderly people" (WHO 2014; p. 11).[1] For this reason, attempting to understand how climate change may affect the health status of vulnerable populations is important for re-directing and prioritizing public resources aimed at preventing and treating climate change induced diseases. A more accurate assessment of such impacts could improve the reliability of predictions of future health burdens caused by climate change, which would allow health stakeholders to make cost-effective decisions regarding long-term health policies.

In this paper, we attempt to understand how temperature variability can affect fetal health. An ample body of literature documents that health at birth is an important determinant of physical development at early stages of life, as well as scholastic achievement, completed years of education, IQ, and labor market outcomes.[2] Recent evidence indicates that fetal health is impaired by a longer exposure to high temperature levels during pregnancy (Dêschenes et al. 2009), yet little is known about how temperature variability can affect health condition at birth.

[1] In the early 2000s the WHO reported that climate change was responsible for roughly 2.4 percent of worldwide diarrhea in low- and middle-income countries - a disease that is known to be one of the leading causes of infant mortality (Gordon et al. 2004).

[2] See, for example, Behrman and Rosenzweig (2004), Black et al. (2007), Royer (2009), Oreopoulos et al. (2008) and more recently Figlio et al. (2014), and Saldarriaga (2015).

We focused on three countries in the Andean region: Bolivia, Colombia, and Peru. Focusing on the Andean region offers at least three advantages for empirical research. First, this region is characterized by a wide range of micro-climates and geographical features, making some localities more likely than others to be affected by climate change. Second, these are developing countries and estimates arising from such countries are less likely to be affected by the use of adaptation technologies. Finally, the Andean region is one of the regions that experts have predicted will be most affected by climate change in the future, (Brooks and Adger 2003; Kreft et al. 2014) ; this makes it particularly important to estimate the effects of climate change on fetal health there.

To study how changes in temperature variability affect fetal health, we construct a novel link between databases of historical global temperatures and health conditions at birth. In particular, we combine global geo-referenced (gridded) monthly temperatures at a resolution of 0.5 x 0.5 degrees (each degree corresponds to approximately 56 kilometers at the equator) over the period 1900-2010 with indicators for neo-natal health from the Demographic and Health Surveys. This information allows for exploring whether and how random (unpredicted) variation in the air temperature during pregnancy affects a range of birth outcomes including birth weight, size at birth, amid others.

Exploiting inter-annual variation in the temperature levels within municipalities and seasons of the year, we estimate that a one standard deviation increase in temperature relative to the long-term local temperature mean reduces birth weight by 20 grams and increases the probability a baby is born with low birth weight by 10 percent. These results are mainly driven by an increased temperature variability observed during the first trimester of pregnancy. In particular, we find that a 1.5 standard deviation above the historical local temperature mean during months 6-8 before birth reduces birth weight by 42.5 grams.

We also find some evidence indicating that these results might be explained by problems associated with food security and health care during pregnancy that intensify with temperature variability. In fact, our results indicate that health condition at birth is more affected in municipalities that are less exposed to agricultural activities. Our results also indicate that an increase in temperature variability reduces the probability of medical assistance during labor. Yet, whether these effects are driven by the demand or supply side of health care remains unclear.

The paper proceeds as follows. In section 2, we describe the empirical evidence about the effects of climate change on fetal health and briefly discuss how temperature variability has changed in the Andean region during the last decades. In section 3, we describe our sources of information and the empirical approach used to uncover the effects of temperature variability on health at birth. In section 4, we present our main results, different sensitivity and placebo checks to test the robustness of our results, and the analysis of some potential channels that might explain the results. The conclusions are presented in section 5.

2. Background

2.1. Temperature and fetal health

Increased temperature levels can affect human health through different channels. The medical literature has distinguished at least five channels through which fetal health can be affected by temperature levels: (i) diseases which are related to changes in the temperature levels *per se* (i.e., respiratory diseases); (ii) exposure to extreme temperatures; (iii) transmission of infectious diseases that are caused by biological vectors; (iv) maternal mental illnesses; and (v) food insecurity resulting from negative agricultural shocks induced by higher temperatures (WHO 2003; McMichael et al. 2007; NIEHS 2010).

An increasing body of evidence documents that fetal health is negatively affected by *in utero* exposure to high temperature levels (Dêschenes et al. 2009; Andalón et al. 2014). Rainfall shocks (Pereda et al. 2014; Rabassa et al. 2014; Rocha and Soares 2015), natural disasters (Simeonova 2011; Currie and Rosin-Slater 2013), and vector borne diseases (Barreca 2010), are all consequences of climate change and increasing temperature levels that have also been found to impair fetal health. Yet, there is no evidence suggesting that exposure to high temperatures during pregnancy affects the health condition in adulthood (Agüero 2014).

Temperature variability is defined as deviations of the temperature level relative to the long-term local temperature mean. Unlike an increasing temperature mean, this definition implies an increase in the variance of the distribution of temperature levels over time. The Third Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) posits that increased temperature variability would increase the probability of observing both cold and hot weathers on a more regular basis.

As such, temperature variability reduces the ability organisms have to predict seasonal changes over time. This loss of ability can potentially modify biological patterns, reducing survival rates of some organisms and increasing those of others. For instance, plants are adapted to use temperature to tell the season and therefore to produce flowers or fruits. An increase in temperature variability implies that plants will experience cold and warm temperatures over relatively short periods of time and as a result they may produce flowers too early or too late, so there might be years in which certain crops cannot be harvested.

In recent years, ecologists have been exploring how temperature variability affects the survival rates and performance of different species. Recent experimental evidence suggest that increases in the variance of daily temperatures while keeping the average temperature constant reduces survival rates of invertebrate species (Vasseur et al. 2014).[3] Yet, there is no evidence about the effects of temperature variability on human health.

[3] Early explorations have experimented with invertebrate ectotherms including fishes, amphibians, reptiles, etc.

2.2. Temperature variability in the Andean region

The weather information for the Andes over the period between 1950 and 2010 provides three specific facts on how the Andean region has been affected by climate change. First, there has been an increase in the regional average temperature. Second, this increase in the average hides important geographical differences, with some communities being severely affected. Lastly, there has been an increase in weather variability causing an intensification of extreme temperature anomalies.

Figure 1 summarizes these facts. It presents the distribution of municipalities according to temperature anomalies observed during the decades 1950-1960 and 2000-2010. For purposes of comparability, temperature anomalies are presented in standard deviations relative to the reference period 1951-1980. Relative to the distribution of temperature anomalies observed in 1950-1960, the 2000-2010 distribution presents a higher temperature mean and variance. This change in the distribution of temperatures suggests that there has been an increase in the probability of observing hot waves in the Andean region in recent years.

To provide a more specific idea of the magnitude, the average temperature in Andean countries has increased by more than 0.5 ºC in the last fifty years.[4] However, this trend hides important differences that display across municipalities. Figure 2 shows the average change in temperature between the decades 1950-1960 and 2000-2010 for the three countries. In general, most of the municipalities have shown an increase in temperature levels in the last half century, but some of them have experienced a more dramatic change over time, with average temperatures rising by more than one degree (when compared to the average global level of roughly 1 degree Celsius).

As for temperature variability, Figure 3 shows the percentage of municipalities experiencing unusual temperatures (i.e., one standard deviation above or below the municipality's historical mean) across time. The figure shows a change in the pattern of temperature anomalies: prior to 1970 there was a balance in terms of cold and hot extreme events, with unusually cold events occurring more frequently. Yet, this trend was reversed over the last forty years with extreme anomalies occurring more frequently and often associated with hot rather than cold temperatures.

Together, these events imply significant challenges for inhabitants and policy-makers in the Andean region. Mitigation strategies are hard to implement given the unpredictability of extreme weather shocks brought about by increased temperature variability. The unpredictability of weather shocks also reduces the ability of inhabitants and governments to react. On the governmental side, for instance, the unpredictability of shocks

[4] A recent report estimates that an increase of one degree in the air temperature over normal levels can result in a between 2 and 5 percent increase in deaths caused by heat stress (WHO and WMO 2012).

reduces the capability to provide services in response to extreme weather events; a fact that amplifies the negative effects of climate change on human activity.

3. Methodology

3.1. Data

Historical temperatures

The information on historical temperature levels is taken from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009). This dataset provides global geo-referenced (gridded) information of the air temperature on a monthly basis for the period between 1900 and 2010 at a resolution of 0.5 X 0.5 degrees (each degree corresponds to approximately 56 kilometers at the equator). Monthly average temperatures for each temperature *node*, which we hereafter will simply call *node*, were interpolated using information from 20 nearby weather stations. Figure 4 plots the distribution of the *nodes* as well as the municipality centroids on the geographic coordinate system, where the horizontal axis represents the longitude and the vertical axis represents the latitude of each point. For each municipality, we assign its corresponding monthly temperature based on the closest *node* to the municipality's centroid.

Following the standard literature, we define temperature variability as the fluctuations in the air temperature from each municipality's historical average (Scherrer et al. 2005). The indicator we use to define temperature variability is constructed based on each child's municipality of birth/residence and date of birth and is calculated using the following formula:

$$SD_{myt} = \left[\frac{1}{9}\sum_{\tau=t-8}^{t}\left(temp_{my\tau} - \overline{temp}_m\right)\right]/\sigma_m ,$$

for a child born in municipality m in year y and month t, where $t = \{1,2,\dots,12\}$. The variable $temp_{my\tau}$ is the average monthly temperature in the corresponding municipality for the τ-th month before the child's month of birth, $\overline{temp}_m$ is the municipality's historical temperature mean for the period 1950-2010, and σ_m is the standard deviation of the municipality's temperature observed for this time period. To put it into words, SD_{myt} indicates the number of standard deviations, on average, during the nine months before the child's date of birth with respect to the municipality's historical temperature mean. That is, SD_{myt} captures the temperature variability experienced by the child while *in utero*.

Birth outcomes

Birth outcomes are obtained from every available Demographic and Health Survey (DHS) in Bolivia, Colombia, and Peru over the period 1990-2013. The DHS provides detailed information on indicators for neo-natal health including birth weight, size at birth, delivery method, amid other indicators for children aged less than five, and has an overall response rate of roughly 90 percent. Also, since the DHS Program is undertaken in several regions, almost all of the questions included in the questionnaires are similar across the three countries.

We restrict the sample to include only children whose mothers report having lived in the municipality for at least two years before the child's date of birth. This restriction ensures that the mothers are not temporal migrants and that we correctly assign each child with its corresponding average temperature while *in utero*. Because twinning is usually related with a lower weight at birth (Kramer 1987), we drop from the sample children born from multiple births; namely duplets, triplets, etc. We also exclude children whose weight at birth was observed to be below 500 grams or above 6,500 grams, as the medical literature points out that these values are considered to be out of the normal range for birth weight (Doubilet et al. 1997). Finally, we exclude all the children whose mothers were younger than 15 or older than 45 years, so that we ensure that all the children were born during the childbearing age of their mothers and the health condition at birth is not affected by the mother's age (Kramer 1987).

We construct four indicators measuring fetal health. The first indicator is the birth weight, measured in grams. We also construct an indicator for low birth weight defined by the WHO as birth weight of less than 2,500 grams (5.5 pounds). We use information on the size at birth reported by the mothers to construct an indicator, "small at birth", for children whose mothers reported that they were small or very small at birth when compared to other babies. Finally, we construct an indicator for delivery via C-section, as this surgical procedure has been commonly associated with complications during pregnancy.

Table 1 provides summary statistics of the sample used for the empirical analysis. The sample contains information on 86,021 children born up to the year 2010. The average child in the sample was born weighing 3,257 grams and 7 percent of these children were born with low birth weight. Also, 6 percent of the children were observed to be small at birth relative to other newborns, as reported by their mothers. Roughly 17 percent of the children were born via C-section. The average child's temperature was observed to be around 19ºC during pregnancy, with a corresponding temperature variability of 0.11 standard deviations relative to the municipality's historical mean.

Figure 5 depicts the distribution of births by the observed temperature variability level during the nine months before birth along with the change in the distribution of births according to the predicted temperature variability level had the child been born in the same month and municipality during the period 2020-2040.[5] Temperature variability during pregnancy was observed to be within the range [-0.5σ, 0.5σ] for roughly 70% of

[5] Weather forecasts for the period 2020-2040 were obtained from the Community Climate System Model (CCSM3) A2 which was produced by the National Center for Atmospheric Research for the IPPC's Fourth Assessment Report.

children in the sample. Estimates of future temperatures based on the CCSM3-A2 model show that, assuming the same geographical and seasonal distribution of births as well as a constant natality rate, 60% of these children will be exposed to *unusual* temperature levels during pregnancy in the upcoming decades; the majority of them experiencing temperatures above 1.5 standard deviations relative to the reference period.

3.2. Empirical strategy

Inter-annual variation in the temperature within a given municipality and month of the year constitutes the basis of our empirical approach. In practice, we compare children who were born in the same municipality and month, but in different years, so that all factors that equally affect the health of the fetuses whose pregnancies were observed to happen within the same geographic unit and season of the year can be purged. Our empirical strategy considers that, although residents of a given municipality can learn about typical weather conditions during a particular time of the year, they cannot anticipate year-to-year variations in the weather.

With information for child i born in municipality m in year y and month t, we estimate linear regressions of the form:

$$\begin{aligned} h_{imyt} = {} & \beta_0 + \beta_1 SD_{imyt}^{TRIM1} + \beta_2 SD_{imyt}^{TRIM2} + \beta_3 SD_{imyt}^{TRIM3} \\ & + X'_{imyt}\gamma + \phi\, Trend_{ny} + \mu_{my} I_{mt} + \mu_y I_y + \varepsilon_{imyt}\,, \end{aligned} \qquad (1)$$

where h_{imyt} is the birth outcome, SD_{imyt}^{TRIM1} is the indicator for temperature variability in the first trimester of pregnancy (months 6-8 before birth), SD_{imyt}^{TRIM2} and SD_{imyt}^{TRIM3} are the corresponding indicators for temperature variability in the second (months 3-5 before birth) and third (months 0-2 before birth) trimesters of pregnancy, X_{imyt} is a vector of child and maternal characteristics, I_y are year-of-birth fixed effects and $Trend_{ny}$ is a *node*-specific linear time trend.[6] The term ε_{imyt} is an error term capturing all other omitted factors.

We include municipality-by-month-of-birth fixed effects, I_{mt}, in the regressions to account for all observed and unobserved factors equally affecting a given municipality in a particular time of the year. By including municipality-by-month-of-birth fixed effects, we also ensure that the municipality's seasonal mean temperature is kept constant. Thus, we capture the effects of changes in the variance while keeping the (long-term) average temperature within the municipality and month of the year unchanged.

[6] Ideally, we would like to identify the trimester of pregnancy counting forward from the day of conception. Unfortunately the DHS does not provide information about the time of the mother's last menstruation before the child's birth, nor whether the child was born prematurely. Therefore, we are unable to calculate the length of pregnancy. We calculate the trimester of pregnancy counting backwards from the child's date of birth, assuming that all pregnancies lasted 9 months (around 38 weeks). In section 4, we test whether the results are sensitive to variations in the pregnancy length by changing the duration of pregnancies to 7 and 8 months.

Equation (1) provides estimates of the effect of temperature variability on birth outcomes. This specification assumes a linear relationship between the temperature variability and fetal health. Yet, we are also interested in determining whether health at birth is equally affected by fluctuations above or below the long-term local temperature mean.

To test whether birth outcomes are also affected by negative fluctuations in the temperature, we construct five indicators based on the number of standard deviations from the municipality's historical mean. These indicators are constructed according to the following categories: < -1.5σ; [-1.5σ, -0.5σ); [-0.5σ, 0.5σ]; (0.5σ, 1.5σ]; > 1.5σ. This way we allow for a more flexible specification exploiting all the available variations in the data and at the same time we deal with potential non-linearities in the effect of temperature variability on birth outcomes.

We perform regressions based on the following equation:

$$h_{imyt} = \theta_0 + \sum_g \theta_{1,g} I_{imyt}^{g,TRIM1} + \sum_g \theta_{2,g} I_{imyt}^{g,TRIM2} + \sum_g \theta_{3,g} I_{imyt}^{g,TRIM3} + X'_{imyt}\psi + \delta \, Trend_{ny} + \vartheta_{my} I_{mt} + \vartheta_y I_y + e_{imyt} , \quad (2)$$

where the indicators $I_{imyt}^{g,TRIM1}$ denote the temperature variability bins, with $g = \{1, 2, 3, 4, 5\}$, for the first trimester of pregnancy, $I_{imyt}^{g,TRIM2}$ and $I_{imyt}^{g,TRIM3}$ are the corresponding temperature variability bins for the second and third trimester of pregnancy respectively, e_{imyt} is an error term, and the rest of the variables are defined the same as they were in equation (1). Estimates for $\theta_{1,g}$, $\theta_{2,g}$ and $\theta_{3,g}$ should be interpreted relative to the base category 3: the temperature variability bin corresponding to the range [-0.5σ, 0.5σ].

A final note relates to the way we estimate standard errors. Since our source of variation comes from different *nodes*, we report the standard errors clustered at two different levels: the municipality and the *node*. This way, we allow for an arbitrary correlation of the error terms of children within the same municipality or *node* (recall that more than one municipality in the sample can have the same *node*) over time. Our results are also robust when clustering the standard errors at the municipality-by-year-of-birth and *node*-by-year-of-birth level (not shown).

4. Results

4.1. Main results

Table 2 presents the main results of the effects of temperature variability on birth weight measured in grams (column 1), the indicator for low birth weight (column 2), the indicator for being small at birth relative to other babies (column 3), and the indicator for delivery via C-section (column 4) based on estimations following equation (1). Panel A of the table presents the results when temperature variability is measured based on the average of the nine months before the child's birth (whole pregnancy period). In Panel B, the effects of temperature variability on birth outcomes are divided by gestational period (trimester of pregnancy).

The results indicate that exposure to a temperate one standard deviation relative to the municipality's historical temperature mean reduces birth weight by 19.7 grams. Similarly, each standard deviation above the historical local temperature mean increases the probability a child is born with low birth weight by 0.7 percentage point. This figure corresponds to an increase of roughly 10 percent in the prevalence of low birth weight in the region. An alternative interpretation of these results is that 1 out of 10 cases of children born with low birth weight can be attributed to an increase in temperature variability. We also find that changing climate variability increases the probability of being small when compared to other newborns by a 0.9 percentage point (or 15 percent from a baseline of 6 percent). We do not find statistically significant effects for delivery via C-section procedure.

In Appendix Tables A1 to A 3, we replicate the regressions presented in Table 2, but using a different reference period for calculating temperature variability. In Appendix Table A1, we calculate temperature variability by using the average temperature and standard deviations from the period 1951-1980, as this period is commonly used by the World Meteorological Organization for obtaining climate statistics. In Appendix Table A2, we use the reference period 1980-2010 to calculate temperature variability as all children in our sample were born during this time period. In Appendix Table A3, we calculate temperature variability by using the average temperature and standard deviations from the 10 years before the child's date of birth. Results remain unchanged when changing the reference period.

When dividing the effects according to gestational period, the results indicate that the effect of temperature variability on birth weight is concentrated during the 6-8 months before birth, corresponding to the first trimester of pregnancy or the embryonic period. In particular, a one standard deviation increase in the temperature relative to the local long-term mean during months 6 to 8 before birth reduces birth weight by 16.5 grams (roughly 84 percent of the overall effect). We do not find statistically significant effects in a particular trimester of pregnancy for the remaining outcomes. Taken together, the results suggest that the effects of temperature variability on birth outcomes may not be driven by the effects in a particular gestational period, but are likely to represent the overall temperature variability experienced during the full gestational period.[7]

[7] We do not discard the possibility of attenuation bias due to measurement error when constructing the temperature variability by gestational period. We interpret our results as being a lower bound (in absolute terms) of the effects of temperature variability in each trimester of pregnancy on birth outcomes, as the recent literature suggests (Currie and Rossin-Slater 2013).

Next, we consider how the estimates vary according to different segments of the temperature variability distribution. The resulting coefficients for birth weight measured in grams based on equation (2) are presented in Table 3.[8] Column 1 presents estimates of the effect of temperature variability on birth weight for months 6-8 before birth (first trimester of pregnancy) while columns 2 and 3 do the same for months 3-5 and months 0-2 before birth, corresponding to the second and third trimesters of pregnancy respectively. In column 4, we present the estimates related to the effect of temperature variability during the full gestational period on birth weight.

The results indicate that a temperature variability level of 1.5 standard deviations above the historical local temperature during the first trimester of pregnancy reduces birth weight by 42.5 grams relative to the *normal* range of temperature variability. We do not find statistically significant effects for temperature variability levels below the historical local mean. Also, no statistically significant effects are found for months 0-5 before birth in any of the temperature variability bins. The results of the effects of temperature variability during the nine months before birth (whole pregnancy period) on birth weight indicate that birth weight is more affected when the distributional changes in the temperature levels are positive rather than negative. In particular, birth weight is reduced by 20.2 grams when the temperature variability level during pregnancy was in the (0.5σ-1.5σ] range and is reduced by 67.4 grams when the temperature variability level during pregnancy was observed to be above 1.5σ relative to the municipality's historical mean.

4.2. Robustness checks

We conduct a series of sensitivity and placebo tests to verify the robustness of our results. In Table 4, we present the results for the whole pregnancy period when controlling for rainfall and migration status of the mother in the regressions. In Appendix Table A4, we present the results for each specific trimester of pregnancy. In columns 1 to 4 of Table 4, we include the rainfall level during the whole pregnancy period as an additional control variable in the regressions. Because temperature and precipitation are intrinsically related, we include precipitation as a regressor in order to discard any possibility that the results are driven by the rainfall, rather than the temperature variability, itself. The coefficients do not change significantly when including this indicator.

In columns 5 to 8 of Table 4, we perform the sensitivity analysis for migration status. Migration status is important since pregnant women can move across locations as a result of the weather conditions. If this were the case, the temperature level assigned to children born to migrant mothers might be incorrect. We define non-migrant mothers as those who have always lived in the current municipality of residence. The results remain unchanged when varying the sample accordingly.

[8] Results for the remaining outcomes are not presented but are available upon request.

We also check whether the results are robust when varying the duration of the pregnancy to seven and eight months. These results are reported in Table 5. In short, we find that the estimated coefficients associated with temperature variability during the full pregnancy period (Panel A) do not change when adjusting the length of pregnancy. When dividing the effects by gestational period (Panel B), we find that exposure to an increase in the temperature variability level during the 6-7 months before birth reduces birth weight by 17.7 grams and exposure to an increase in the temperature variability during the 6 months before birth reduces birth weight by 14.1 grams. We do not find statistically significant effects in a particular trimester of pregnancy for the rest of the outcomes.

Lastly, we perform placebo tests to check for whether the results are being driven by other channels than the temperature variability during pregnancy. In Table 6, we present the results for temperature variability during the whole pregnancy period on birth outcomes when temperature variability during months 12-23 before the child's birth and during months 1-12 after the child's birth are included as additional controls. The effect of temperature variability during pregnancy on fetal health remains unchanged even after controlling for temperature variability before conception and after birth. Moreover, we do not find statistically significant effects of temperature variability before or after pregnancy on birth outcomes. These results suggest that fetal health is only affected by temperature variability during the time *in utero* and not by other factors potentially related to climate variability.

4.3. Channels

We explore potential channels through which temperature variability can affect fetal health. We consider two channels: food insecurity and health care during pregnancy. Temperature variability can affect agricultural yields and decrease the stock of food (Cline 1996; Dêschenes and Greenstone 2007; McMichael et al. 2007), affecting maternal nutrition and therefore fetal health (Almond and Mazumder 2011; Hernández-Julián et al. 2014). Also, extreme weather events caused by increased temperature variability can destroy roads and isolate populations, restricting the access to health facilities.

To measure the effect of food insecurity on fetal health, we construct indicators measuring the cultivated land as a percentage of the total area in the municipality during the 2000s.[9] We then perform regressions including the interaction term between the indicator for temperature variability and the indicators for the municipality's exposure to agricultural activities in regressions following equation (1). In the interest of brevity, we present the results for the whole pregnancy period in Table 7.

[9] Information for cultivated land in the municipality was obtained from the Harmonized World Soil Database V1.2. This publicly available raster dataset is produced by the Food and Agriculture Organization of the United Nations (FAO) and provides estimates of the land cover and land use at a 30 arc-second resolution.

Estimated coefficients associated to the interaction terms are negative and statistically significant for the regressions of low birth weight (see column 2 in Table 7). Moreover, these coefficients increase (in absolute terms) with the percentage of land used for agriculture, indicating that the effect of temperature variability is *lower* when the municipality is more exposed to agricultural activities. A potential interpretation for this result is that food producers re-allocate their products for self-consumption after observing an increase in temperature variability. This re-allocation of food production would mitigate the negative effects of temperature variability on the nutrition of pregnant women in municipalities with higher levels of agricultural activity.

Finally, we explore whether increased temperature variability can lead to changes in health care during pregnancy. In Table 8, we show the results of exposure to temperature variability while *in utero* on the number of pre-natal checkups (column 1), institutional delivery (column 2), and specialized medical assistance during labor (column 3).[10] Results indicate that a temperate one standard deviation above the historical local temperature mean reduces the probability of medical assistance during labor by a 0.9 percentage point. Yet, we do not find statistically significant effects for pre-natal checkups, nor for institutional delivery.

5. Final remarks

The discussion on the effects of climate change on human activity has primarily focused on how increased temperatures can impair human health. Yet, less attention has been paid to the impact of mean-preserving distributional changes of climate over time. This research sheds light on the adverse effects of temperature variability on health conditions of newborns.

We employed information on historical geo-referenced monthly temperatures and health conditions at birth to explore how *in utero* exposure to temperature variability affects birth outcomes in the Andean Region - a region predicted to be one of the most affected by climate change in the future. Our empirical strategy exploits inter-annual variation in the temperature levels within municipalities and season of the year, considering that these variations are mainly unpredicted.

Our results indicate that a one standard deviation increase in the long-term local temperature mean reduces birth weight by 20 grams and increases the probability a baby is born with low birth weight by 10 percent. These results are mainly driven by an increased temperature variability observed during the first trimester of pregnancy. In particular, we find that a 1.5 standard deviation above the historical local temperature mean during months 6-8 before birth reduces birth weight by 42.5 grams.

[10] Institutional delivery is an indicator taking the value of 1 if the child was born in a public managed hospital, public or private managed health care centers, hospitals belonging to NGOs or religious organizations, or medical posts, and 0 in any other case. Specialized medical assistance is an indicator taking the value of 1 if delivery was assisted by a physician, obstetrician, or trained nurse and 0 in any other case.

We find some evidence that these results might be explained by food insecurity and health care during pregnancy that arises due to increased temperature variability. Our findings are robust to the performance of different sensitivity analysis and falsification tests. We argue that these results are more likely to mirror the actual effects of climate change on birth outcomes, since the use of adaptation technologies is not widespread in developing countries.

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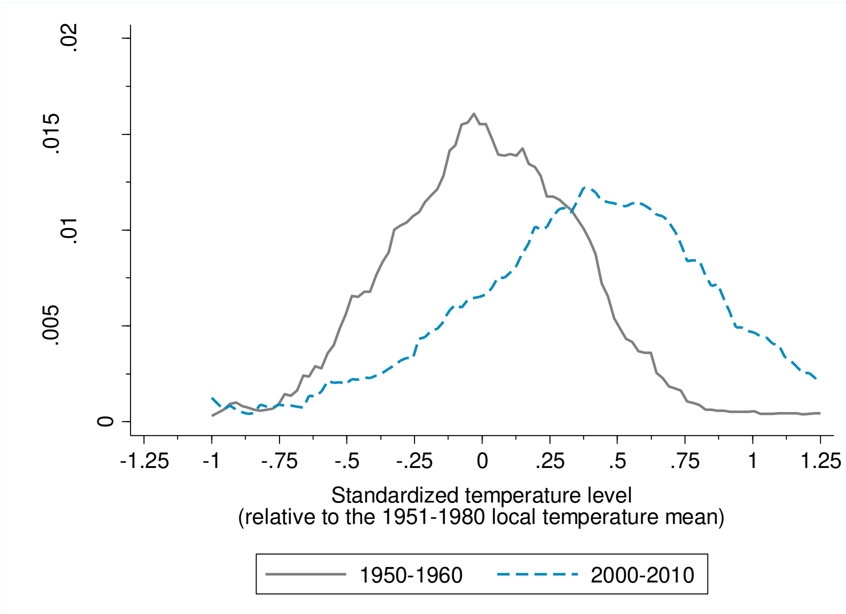
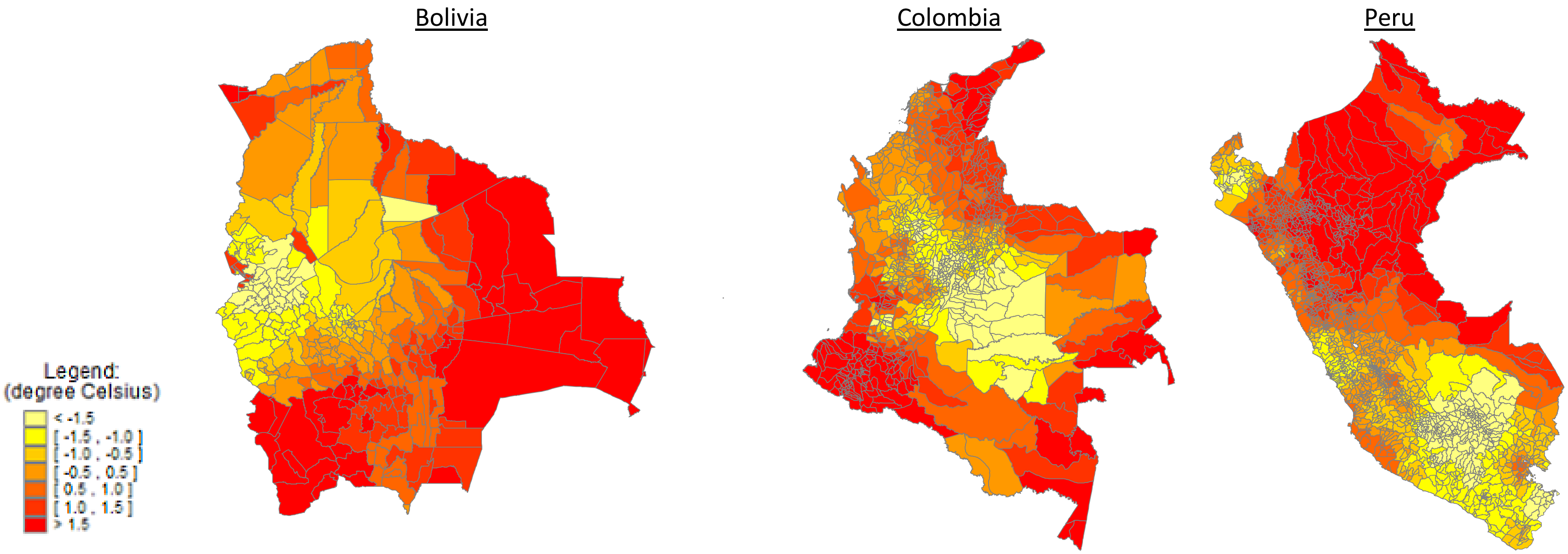
Figure 1
Distribution of temperatures relative to the 1951-1980 period



Notes: The figure shows the distribution of temperatures in municipalities in the Andean region (Bolivia, Colombia, and Peru) for the decades of 1950-1960 and 2000-2010. Temperatures were normalized based on each municipality's average temperature and its corresponding standard deviation for the period 1951-1980.

Source: Own calculations based on the Global Administrative Areas (GADM) version 2.6 and *Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01* (Mattsura y Willmott 2009).

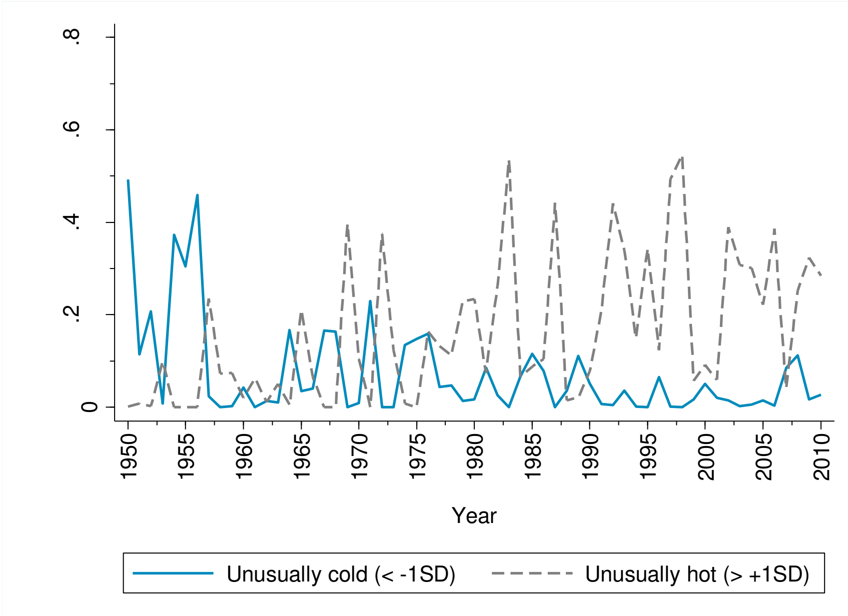
Figure 2
Temperature Change 1950-60 / 2000-2010



Notes: The figure shows the change in the average temperature in each municipality in the decade 2000-2010 relative to that of the decade 1950-1960 for Bolivia, Colombia, and Peru.
Source: Own calculations based on the Global Administrative Areas (GADM) version 2.6 and *Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01* (Mattsura y Willmott 2009).

Figure 3

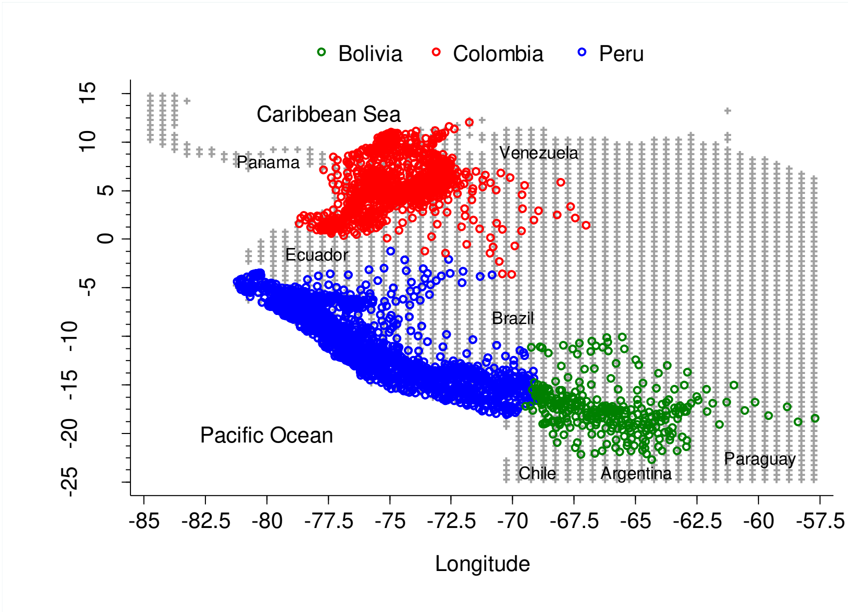
Extreme temperatures in the Andean region (1950-2010)



Notes: The figure shows the percentage municipalities (*N* = 3,204) in the Andean region (Bolivia, Colombia, and Peru) with 1 standard deviation above or below the local mean for the period 1950-2010. The reference period for calculating the municipality's mean temperature and standard deviation corresponds to 1951-1980.

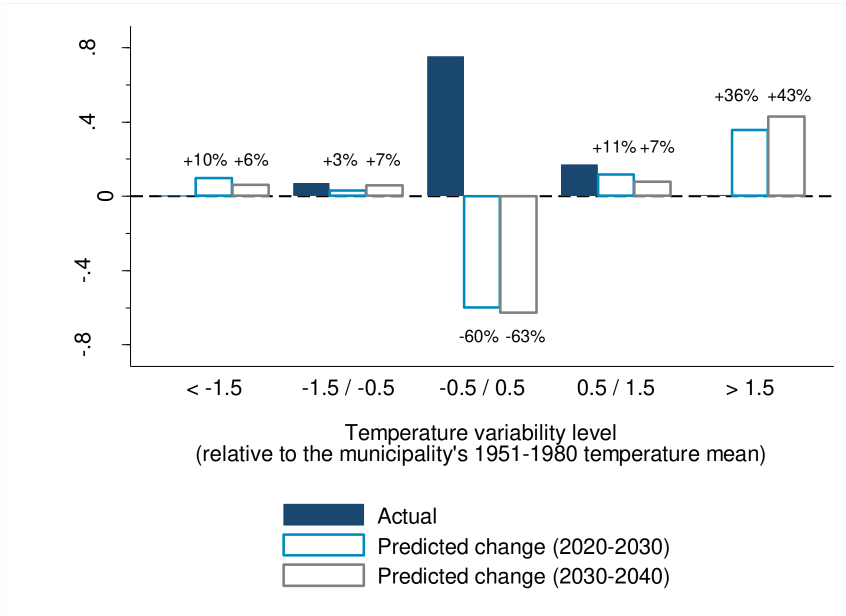
Source: Own calculations based on the Global Administrative Areas (GADM) version 2.6 and *Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01* (Mattsura y Willmott 2009).

Figure 4
Distribution of municipality centroids and temperature *nodes* on the coordinate plane



<u>Notes</u>: The figure shows the distribution of the municipality centroids for Bolivia (green), Colombia (red), and Peru (blue) and the temperature *nodes* (grey) along the geographic coordinate system.
Source: Global Administrative Areas (GADM) version 2.6 and *Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01* (Mattsura y Willmott 2009).

Figure 5
Fraction of births by temperature variability level during pregnancy
(current and future estimates)



Notes: The figure shows the fraction of births by observed temperature variability level during pregnancy and the predicted change in the distribution of births by temperature variability level according to the forecasted temperatures for the periods 2020-2030 and 2030-2040.
Source: Own calculations based on the Demographic and Health Surveys, *Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01* (Mattsura y Willmott 2009) and CCSM3 A2 – National Center for Atmospheric Research.

Table 1
Summary statistics

Variable	Mean	Standard deviation	Range [min. - max.]
Birth weight (grams)	3257.16	598.71	[500.00 - 6,500.00]
Low birth weight (< 2,500 grams)	0.07	0.26	[0,1]
Small at birth	0.06	0.24	[0,1]
Delivered via C-section procedure	0.17	0.37	[0,1]
Average temperature (°C): 9 months before birth	19.32	6.30	[-4.91 - 31.48]
Temperature variability*: 9 months before birth	0.11	0.49	[-2.78 - 3.20]
Temperature variability: months 8-6 before birth (1st. Trimester)	0.12	0.87	[-4.51 - 3.94]
Temperature variability: months 5-3 before birth (2nd. Trimester)	0.11	0.87	[-4.51 - 3.94]
Temperature variability: months 2-0 before birth (3rd. Trimester)	0.11	0.88	[-4.51 - 3.79]
Child is male	0.51	0.50	[0,1]
Child's birth order	3.10	2.28	[1.00 - 19.00]
Birth weight information obtained from the birth certificate	0.23	0.42	[0,1]
Mother's current age	29.45	7.01	[15.00 - 49.00]
Mother's age at child's birth	26.91	6.84	[15.00 - 45.00]
Mother's age at 1st. birth	20.14	4.22	[9.00 - 45.00]
Mother's schooling	7.50	4.47	[0.00 - 18.00]
Mother's height (cm.)	1.52	0.06	[1.30 - 1.98]
Lives in urban areas	0.57	0.50	[0,1]

(*) Standard deviations from the municipality's historical temperature mean (average temperature for the period 1950-2010).

Table 2

Effects of temperature variability on birth outcomes (reference period: 1950-2010)

	(1)	(2)	(3)	(4)
	Dependent variable:			
	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
	Panel A: Whole pregnancy period			
Temperature variability	-19.676	0.007	0.009	0.007
	(7.462)***	(0.004)*	(0.004)**	(0.008)
	[6.945]***	[0.004]**	[0.004]**	[0.009]
	Panel B: By gestational period			
Temperature variability:				
Months 6-8 before birth	-16.455	0.003	0.003	0.002
(Embryonic period)	(6.909)**	(0.004)	(0.004)	(0.007)
	[6.429]**	[0.003]	[0.003]	[0.007]
Months 3-5 before firth	-10.275	0.005	0.006	0.003
(Fetal period)	(9.802)	(0.004)	(0.004)	(0.006)
	[9.870]	[0.004]	[0.004]	[0.007]
Months 0-2 before birth	6.943	-0.001	-0.000	0.002
(Pre-natal period)	(9.400)	(0.003)	(0.004)	(0.007)
	[9.391]	[0.003]	[0.004]	[0.008]
N	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each entry in Panel A and each column in Panel B comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Additional features of each specification are described within the table. All the regressions include a *node* specific linear time trend, an indicator for the child's sex, indicators for the child's year of birth (1991-1995, 1996-2000, 2001-2005, 2006+; base: born in 1990 or before), indicators for the child's birth order (2, 3, 4, 5+; base: firstborn), an indicator for birth weight information recorded from the birth certificate, indicators for the mother's year of birth (1951-1955, 1956-1960, 1961-1965, 1966-1970, 1971-1975, 1976-1980, 1981-1985, 1986-1990, 1991-1995; base: born in 1950 or before), indicators for the mother's age at the time of the child's birth (21-29, 30-29, 40-45; base: 20 or less), indicators for the mother's age at first birth (21-29, 30-29, 40-45; base: 20 or less), indicators for the mother's height (1.30-1.39cm., 1.40-1.49cm., 1.50-1.59cm., 1.60-1.69cm., 1.70-1.79cm., 1.80cm. or more; base: missing information on the mother's height), indicators for the mother's educational attainment (incomplete primary, primary, incomplete secondary, high school diploma, some college or more education; base: no education), and an indicator for living in urban areas as control variables. The sample used for the regressions include children born up to year 2010, born from single pregnancies (non-twins), ages 0-59 months, whose weight at birth was between 500 and 6,500 grams, whose mothers were between 15 and 45 years (childbearing age) at the time of the child's birth, and whose mothers reported having been living in the municipality since at least two years before the child's birth. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table 3

Effects of temperature variability on birth weight, by temperature variability level

	(1)	(2)	(3)	(4)
	Effect of change in temperature variability during:			
	Months 6-8 before birth	Months 3-5 before birth	Months 0-2 before birth	Whole pregnancy
Temperature variability range:				
< -1.5σ	-2.482	19.608	-8.483	1.959
	(29.152)	(24.464)	(24.108)	(44.935)
	[29.819]	[22.565]	[23.366]	[30.164]
[-1.5σ , -0.5σ)	14.595	9.235	-7.771	-2.016
	(9.988)	(11.189)	(12.074)	(14.706)
	[9.972]	[13.108]	[11.145]	[13.746]
(0.5σ , 1.5σ]	-10.910	-20.053	17.564	-20.161
	(10.087)	(13.176)	(12.799)	(10.536)*
	[9.723]	[13.032]	[12.216]	[10.506]*
> 1.5σ	-42.498	-21.506	-0.943	-67.442
	(21.458)**	(23.268)	(19.042)	(27.615)**
	[19.712]**	[24.475]	[20.239]	[25.072]***

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. All the coefficients come from a single regression based on equation (2). Clustered standard errors at the municipality level are reported in parentheses (1,947 clusters). Clustered standard errors at the *node* level are reported in brackets (614 clusters). The number of observations in each column is 86,021. All the coefficients reported in the table are interpreted relative to the base category of temperature variability [-0.5σ , 0.5σ] and are estimated using the sample weights from the DHS. The indicators for temperature variability levels are calculated based on the municipality's historical mean (average temperature for the period 1950-2010). See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table 4

Sensitivity analysis: Controlling for rainfall and migration status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Rainfall during pregnancy				Migration status			
Dependent variable:	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
Temperature variability	-21.709	0.008	0.009	0.003	-29.252	0.010	0.010	0.011
	(8.566)**	(0.004)*	(0.005)**	(0.008)	(10.282)***	(0.006)*	(0.006)*	(0.012)
	[8.076]***	[0.004]*	[0.004]**	[0.009]	[10.379]***	[0.006]*	[0.006]*	[0.013]
Rainfall during pregnancy	-22.001	0.003	0.002	-0.040				
(x 100mm.)	(26.302)	(0.010)	(0.010)	(0.011)***				
	[26.510]	[0.010]	[0.010]	[0.011]***				
N	86,021	86,021	86,021	86,021	48,034	48,034	48,034	48,034
Clusters (municipality)	1,947	1,947	1,947	1,947	1,869	1,869	1,869	1,869
Clusters (*node*)	614	614	614	614	602	602	602	602
Sample weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None	Non-migrants	Non-migrants	Non-migrants	Non-migrants

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each column comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Additional features of each specification are described within the table. The sample used for regressions in columns (5) to (8) only includes children whose mothers have always lived in the municipality (non-migrants). See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table 5
Sensitivity analysis: Changing the duration of pregnancy

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pregnancy length: 8 months				Pregnancy length: 7 months			
Dependent variable:	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
	Panel A: Whole pregnancy period							
Temperature variability	-17.476	0.007	0.008	0.007	-15.236	0.006	0.008	0.007
	(7.101)**	(0.004)*	(0.004)**	(0.008)	(6.844)**	(0.004)	(0.004)*	(0.008)
	[6.550]***	[0.003]*	[0.004]**	[0.009]	[6.391]**	[0.003]*	[0.003]**	[0.008]
	Panel B: By gestational period							
Temperature variability:								
Months 6-7 before birth	-17.701	0.006	0.006	0.007				
	(6.544)***	(0.004)	(0.004)	(0.006)				
	[6.955]**	[0.004]	[0.004]	[0.006]				
Month 6 before birth					-14.133	0.003	0.003	0.006
					(5.806)**	(0.004)	(0.004)	(0.005)
					[5.527]**	[0.004]	[0.004]	[0.006]
Months 3-5 before birth	-2.496	0.002	-0.001	0.003	1.301	-0.002	-0.005	0.001
	(18.127)	(0.008)	(0.008)	(0.013)	(18.199)	(0.008)	(0.008)	(0.013)
	[20.941]	[0.008]	[0.008]	[0.012]	[19.860]	[0.008]	[0.008]	[0.011]
Months 0-2 before birth	11.095	0.001	-0.000	0.006	12.929	-0.001	-0.002	0.005
	(11.170)	(0.006)	(0.006)	(0.007)	(11.227)	(0.006)	(0.006)	(0.007)
	[12.280]	[0.006]	[0.005]	[0.006]	[11.746]	[0.006]	[0.005]	[0.006]
N	86,021	86,021	86,021	86,021	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None	None	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each entry in Panel A and each column in Panel B comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Additional features of each specification are described within the table. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table 6

Placebo tests

Dependent variable:	(1) Birth weight (grams)	(2) LBW (< 2,500 gr.)	(3) Small at birth	(4) C-section
Temperature variability	-17.204	0.007	0.009	0.007
(whole pregnancy period)	(7.617)**	(0.004)*	(0.004)**	(0.008)
	[7.155]**	[0.004]*	[0.004]**	[0.009]
Temperature variability	-11.543	-0.000	-0.000	-0.005
(months 12-23 before birth)	(7.819)	(0.003)	(0.003)	(0.007)
	[7.780]	[0.003]	[0.003]	[0.006]
Temperature variability	-11.035	0.001	0.002	0.001
(months 1-12 after birth)	(7.673)	(0.003)	(0.003)	(0.007)
	[8.052]	[0.003]	[0.003]	[0.006]
N	85,709	85,709	85,709	85,709
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each column in the table comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability in each period is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Additional features of each specification are described within the table. The number of observations is smaller than that from Table 2 because children born in year 2010 are not included in the regressions as we do not observe information for temperatures on the months 1-12 after birth for these children. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table 7
Channels: Exposure to agricultural activities

	(1) Birth weight (grams)	(2) LBW (< 2,500 gr.)	(3) Small at birth	(4) C-section
Temperature variability	-26.384	0.015	0.016	-0.000
(whole pregnancy period)	(10.334)**	(0.005)***	(0.005)***	(0.015)
	[10.447]**	[0.005]***	[0.006]***	[0.015]
Temperature variability	9.953	-0.013	-0.012	0.008
X Land used for agriculture: 20% or less	(15.439)	(0.007)*	(0.007)	(0.019)
	[14.922]	[0.007]*	[0.007]	[0.019]
Temperature variability	31.343	-0.028	-0.021	0.044
X Land used for agriculture: 20%-40%	(30.006)	(0.013)**	(0.014)	(0.022)**
	[30.508]	[0.013]**	[0.014]	[0.022]**
Temperature variability	-57.015	-0.051	-0.060	-0.009
X Land used for agriculture: 40% or more	(126.967)	(0.020)***	(0.023)***	(0.055)
	[127.229]	[0.020]***	[0.023]***	[0.055]
N	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each column in the table comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Indicators for exposure to agricultural activities are constructed based on the cultivated land in the municipality during the 2000s (as a percentage of the municipality's total area). The base category for the percentage land used for agriculture is 0% (no land used for agricultural activities). Additional features of each specification are described within the table. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013), from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009), and from the FAO Harmonized World Soil Database V1.2.

Table 8

Channels: Health care during pregnancy

	(1)	(2)	(3)
	Dependent variable:		
	Pre-natal checkups (number)	Institutional delivery	Medical assistance during labor
Temperature variability	-0.058	0.004	-0.009
(whole pregnancy period)	(0.051)	(0.007)	(0.003)***
	[0.055]	[0.006]	[0.004]***
N	70,505	86,021	86,021
Clusters (municipality)	1,941	1,947	1,947
Clusters (*node*)	613	614	614
Sample weights	Yes	Yes	Yes
Sample restrictions	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each entry in the table comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). The sample size in column 1 is smaller than the sample size in other columns because the number of pre-natal checkups is only available for the lastborn child in the DHS datasets. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Appendix

Table A1

Effects of temperature variability on birth outcomes (reference period: 1951-1980)

	(1)	(2)	(3)	(4)
	Dependent variable:			
	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
	Panel A: Whole pregnancy period			
Temperature variability	-19.089	0.007	0.009	0.007
	(7.075)***	(0.004)*	(0.004)**	(0.008)
	[6.546]***	[0.003]**	[0.003]**	[0.008]
	Panel B: By gestational period			
Temperature variability:				
6-8 months before birth	-15.765	0.003	0.002	0.002
(Embryonic period)	(6.592)**	(0.004)	(0.004)	(0.006)
	[6.077]***	[0.003]	[0.003]	[0.006]
3-5 months before birth	-9.711	0.005	0.006	0.003
(Fetal period)	(9.476)	(0.004)	(0.004)	(0.006)
	[9.557]	[0.003]	[0.004]*	[0.006]
0-2 months before birth	6.246	-0.001	-0.000	0.002
(Pre-natal period)	(9.160)	(0.003)	(0.004)	(0.007)
	[9.171]	[0.003]	[0.003]	[0.008]
N	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each entry in Panel A and each column in Panel B comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's 1951-1980 temperature mean. Additional features of each specification are described within the table. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table A2

Effects of temperature variability on birth outcomes (reference period: 1980-2010)

	(1)	(3)	(4)	(5)
	Dependent variable:			
	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
	Panel A: Whole pregnancy period			
Temperature variability	-19.048	0.007	0.008	0.007
	(7.518)**	(0.004)	(0.004)**	(0.008)
	[7.030]***	[0.004]*	[0.004]**	[0.009]
	Panel B: By gestational period			
Temperature variability:				
6-8 months before birth	-16.003	0.003	0.003	0.002
(Embryonic period)	(7.042)**	(0.004)	(0.004)	(0.007)
	[6.817]**	[0.003]	[0.003]	[0.007]
3-5 months before birth	-10.596	0.005	0.006	0.002
(Fetal period)	(9.640)	(0.004)	(0.004)	(0.006)
	[9.683]	[0.003]	[0.004]*	[0.007]
0-2 months before birth	7.492	-0.001	-0.001	0.002
(Pre-natal period)	(9.214)	(0.003)	(0.004)	(0.007)
	[9.179]	[0.003]	[0.004]	[0.008]
N	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: Each entry in Panel A and each column in Panel B comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's 1980-2010 temperature mean. Additional features of each specification are described within the table. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table A3
Effects of temperature variability on birth outcomes
(reference period: 10-year period before child's birth)

	(1)	(3)	(4)	(5)
	Dependent variable:			
	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
	Panel A: Whole pregnancy period			
Temperature variability	-14.253	0.007	0.008	0.007
	(7.096)**	(0.004)*	(0.004)**	(0.008)
	[6.638]**	[0.003]**	[0.003]**	[0.008]
	Panel B: By gestational period			
Temperature variability:				
6-8 months before birth	-13.963	0.004	0.003	0.003
(Embryonic period)	(6.778)**	(0.004)	(0.004)	(0.007)
	[6.302]**	[0.003]	[0.003]	[0.007]
3-5 months before birth	-8.733	0.004	0.006	0.001
(Fetal period)	(8.975)	(0.004)	(0.004)	(0.006)
	[8.947]	[0.003]	[0.004]	[0.006]
0-2 months before birth	7.767	-0.001	-0.001	0.003
(Pre-natal period)	(8.297)	(0.003)	(0.003)	(0.007)
	[8.385]	[0.003]	[0.003]	[0.007]
N	86,021	86,021	86,021	86,021
Clusters (municipality)	1,947	1,947	1,947	1,947
Clusters (*node*)	614	614	614	614
Sample weights	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None

Notes: Each entry in Panel A and each column in Panel B comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's average temperature during the 10 years prior to the child's birth. Additional features of each specification are described within the table. See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).

Table A4

Sensitivity analysis: Controlling for rainfall and migration status (by gestational period)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Rainfall during pregnancy				Migration status			
Dependent variable:	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section	Birth weight (grams)	LBW (< 2,500 gr.)	Small at birth	C-section
Temperature variability:								
Months 6-8 before birth	-16.247	0.003	0.003	0.003	-17.048	0.004	0.004	0.002
(Embryonic period)	(6.845)**	(0.004)	(0.004)	(0.007)	(9.397)*	(0.006)	(0.006)	(0.010)
	[6.405]**	[0.003]	[0.003]	[0.007]	[9.817]*	[0.006]	[0.005]	[0.009]
Months 3-5 before firth	-10.835	0.005	0.006	0.001	-8.846	0.000	0.001	0.004
(Fetal period)	(10.124)	(0.004)	(0.004)	(0.006)	(12.418)	(0.006)	(0.006)	(0.010)
	[10.262]	[0.004]	[0.004]	[0.007]	[12.564]	[0.006]	[0.006]	[0.009]
Months 0-2 before birth	5.766	-0.001	-0.000	-0.1	-3.771	0.006	0.005	0.005
(Pre-natal period)	(9.126)	(0.004)	(0.004)	(0.007)	(12.036)	(0.005)	(0.006)	(0.011)
	[9.015]	[0.003]	[0.004]	[0.008]	[12.071]	[0.005]	[0.005]	[0.011]
Rainfall during pregnancy	-16.979	0.002	0.002	-0.041				
(x 100mm.)	(24.422)	(0.010)	(0.010)	(0.011)***				
	[24.595]	[0.010]	[0.010]	[0.011]***				
N	86,021	86,021	86,021	86,021	48,034	48,034	48,034	48,034
Clusters (municipality)	1,947	1,947	1,947	1,947	1,869	1,869	1,869	1,869
Clusters (*node*)	614	614	614	614	602	602	602	602
Sample weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample restrictions	None	None	None	None	Non-migrants	Non-migrants	Non-migrants	Non-migrants

Notes: ***, **, and * indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. Each column comes from a different regression based on equation (1). Clustered standard errors at the municipality level are reported in parentheses. Clustered standard errors at the *node* level are reported in brackets. The indicator for temperature variability is defined as the number of standard deviations relative to the municipality's historical mean (average temperature for the period 1950-2010). Additional features of each specification are described within the table. The sample used for the regressions in columns (5) to (8) only includes children whose mothers have always lived in the municipality (non-migrants). See the notes on Table 2 for details on other controls included in the regressions and additional sample restrictions. The data used for the regressions come from the Demographic and Health Surveys (DHS) of Bolivia (2003, and 2008), Colombia (1990, 1995, 2000, 2005, and 2010), and Peru (1992, 1996, 2000, 2004, 2008, 2009, 2010, 2011, 2012, and 2013) and from the *Terrestrial Air Temperature: 1900-2010 Gridded Monthly Time Series Version 3.01* (Matsuura and Willmott 2009).