Heat Shocks, Child Endowments, and Parental investments

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RESUMO

Este artigo investiga como a exposição pré-natal a temperaturas extremadamente altas afeta o investimento em capital humano na Colômbia. Usando uma estratégia de efeito-fixos, encontra-se que crianças expostas a estresse de calor durante o segundo trimestre da gravidez são mais propensas a receber as vacinas necessárias e são amamentados por mais tempo. Uma variedade de evidencia é apresentada em favor da interpretação de que esses resultados refletem respostas compensatórias das famílias a mudanças nas dotações inicias das crianças. O artigo também encontra evidencia sugestiva de que os efeitos de estrese de calor pré-natal podem persistir até a vida adulta, o que indica que os aumentos nos investimentos durante a infância não remediam completamente os efeitos de linha base de choques pré-natais de calor.

Palavras-Chave: Eventos extremos de temperatura; dotações iniciais das crianças; Investimentos em capital humano

ABSTRACT

This paper studies how *in utero* exposure to extreme hot temperatures affects parental investments in Colombia. Using a sibling-fixed effects strategy, we show that children who were exposed *in utero* to heat stress during second trimester are more likely to receive necessary vaccines and are breastfed for longer. A variety of evidence is presented in favor of the interpretation that this household behavior reflects a compensatory response to shifts in children's endowments. We also provide suggestive evidence that the effects of prenatal heat stress can last into adulthood, indicating that increased investments during infancy are not sufficient to remedy the baseline effects of *in utero* shocks.

Keywords: Extreme weather events; birth endowments; parental investments.

JEL Codes: D1, I1, J1

ÁREA DE SUBMISSÃO: Economia Social e do Trabalho

1. Introduction

Poor environmental conditions *in utero* can have significant effects on later-life outcomes. Compared to their counterparts, children endowed with poor health are more likely to have lower cognitive abilities, lower educational attainment, and worse health outcomes as adults (Currie and Hyson 1999; Behrman and Rosenzweig 2004; Almond 2006). One intriguing question is how parental behavior responds to shifts in initial endowments. Such parental responses indicate by how much household behavior exacerbate or mitigate the effects of *in utero* shocks. This question has been subject of theoretical debate for a long time. According to Becker and Tomes (1976), if low initial endowment in a child implies lower returns on investments, then parents are likely to adopt reinforcing strategies. Conversely, Behrman et al. (1982) conjecture that when parents care about sibling inequality in welfare, then they would make more human capital investments in the less-endowed child. Ultimately, how parental behavior responds to shifts in initial endowments is an empirical question.

In this paper, we estimate the impact of prenatal exposure to heat waves on health investments using Colombian data. Exposure to extreme high temperatures is believed to be hazardous for health. A pregnant woman is more susceptible to high temperatures due to the additional physical strain and the reduced capacity to lose heat by sweating (Strand, Barnett, and Tong 2011; Wells and Cole 2002). As a result, it has been hypothesized that exposure to heat stress during pregnancy could harm the development of the fetus. Randomized experiments with animals suggest that exogenous exposure to high temperatures *in utero* negatively affects health and the motor development of offspring (Strong et al. 2015; Shiota and Kayamura 1989). A set of recent research in humans also has found suggestive evidence that maternal heat stress during pregnancy has adverse consequences on infant health (Deschenes, Greenstone, and Guryan 2009; Strand, Barnett, and Tong 2011). Altogether, these facts suggest that greater exposure *in utero* to heat waves has the potential to explain low levels of human capital.

The question is especially relevant in view of projections indicating that extreme temperature episodes will increase in the next decades (IPCC 2007). A growing body of recent work has tried to quantify the effects of such climatic shocks on several dimensions, including health and income (Dell, Jones, and Olken 2012; Deschênes and Moretti 2009). However, most of studies focus on the short-term impacts of extreme temperatures. Remarkably, the pathways on how weather events could have long-term impacts are not well-studied. Understanding the parental responses to shifts in endowments induced by prenatal extreme hot temperatures would provide important insights.

Our identification strategy exploits plausibly exogenous variation in temperature over time within municipalities. We construct a municipality-by-month weather dataset, which then is combined with microdata by using date and place of birth to identify the prevailing temperature conditions during pregnancy. The empirical approach then compares parental investments on children that were prenatally exposed to extreme hot temperatures relative to those that experienced less extreme temperature conditions *in utero*. Since the occurrence of a temperature shock at a given moment in time and place is unpredictable, prenatal exposure to heat waves can be considered as good as randomly assigned. In addition, we can control for sibling-fixed effects to address the issue that different types of families may change their fertility decisions based on temperature around the time of conception (Barreca, Deschenes, and Guldi 2015; Wilde, Apouey, and Jung, *Forthcoming*). This research design is particularly suitable for the Colombian context. As hydro-meteorological patterns are affected by a recurrent climatic event, temperature records in Colombia vary widely year to year across municipalities. Furthermore, since agricultural production account for a low share of Colombia GDP, the potential for general equilibrium effects is diminished.

The inputs that we have examined are breastfeeding and vaccination. Both investments are believed to be particularly important for child health in developing countries. Vaccinations such as polio and measles have been shown to be effective in preventing ill health and mortality. Likewise, breastfeeding plays a central role in nutrition, especially in environments characterized by unsafe drinking water and limited supply of food. A large body of work has also documented that breastfeeding is predictive of later cognitive outcomes.[1]

Using the sibling-fixed effects strategy, we document that children who were exposed to heat waves while *in utero* are more likely to receive necessary vaccines and are breastfed for longer. These results are not driven by time-series correlation in temperature, migration, or changes in local economic activity. Furthermore, we find that the quantity and spacing of births are not significantly affected. Therefore, we believe that it may be reasonable to attribute the effects to variations in child endowments. This interpretation is made somewhat more plausible by the evidence that prenatal heat stress has adverse consequences on offspring endowments and by the documented relationship, both theoretically and empirically, between child endowments and parental investments. As such, our findings point out that birth endowments are an unexamined mechanism by which extreme hot temperatures could have long-term impacts on human capital accumulation of cohorts prenatally exposed during these periods.

One implication of these findings is that the long-term impacts of prenatal heat waves on human capital accumulation are not trivial. If early health investments play an important role in the later-life capabilities, the net long-term impact of prenatal hot temperature could become small or even translated into improved human capital accumulation. To shed lights on this issue, we provide reduced-form estimates of the impacts of heat waves on total years of schooling for adults aged 20-36, using census data. We find a small, but statistically significant effect of prenatal exposure to heat waves on educational attainment. Cohorts exposed prenatally to one heat wave received an average of 0.03 fewer years (0.34 per cent) of education. This suggests that the initial shock is not completely offset by the increased health investments during infancy.

Our study contributes to a growing body of knowledge on the links between *in-utero* exposure to environmental shocks and human capital investments (Almond, Edlund, and Palme 2009; Kelly 2011; Venkataramani 2012; Parman 2013). While studies in this area typically focus on uncommon and severe historical events, we focus on an environmental shock that is less drastic but occurs with higher frequency. We see our results as a first attempt to show the systematic importance of heat stress *in utero* on parental investments. Furthermore, most of existing historical studies use limited measures of investments and have used a variety of indirect strategies to infer parental responses. For example, Almond, Edlund, and Palme (2009) argue that parents adopt reinforcing strategies because the effect of fetal exposure to the radioactive fallout on cognitive skills was greater in children from poor families. This evidence is compelling, but not conclusive. In contrast to these studies, we use more direct measures of parental inputs. Our study also builds on the recent work by Adhvaryu and Nyshadham (2014), who find that children with higher exposure to an iodine supplementation program during pregnancy received more health investments in Tanzania.

This paper is also related to a number of previous studies that link parental investments to proxy variables for endowment, such as birth weight. This literature is not conclusive.[2] While some studies find evidence for reinforcement (Datar, Kilburn, and Loughran 2010; Aizer and Cunha 2012), others find that parents respond with compensating behavior (Del Bono, Ermisch, and Francesconi 2012). In part, clear stylized facts are not developed due to the endogeneity issues. Prenatal and postnatal unobserved investments could create a correlation between birth endowments and parental investment, even in the absence of a

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[1] See, for example, Del Bono and Rabe (2012), Anderson, Johnstone, Remley (1999), and Victora et al (2015).
[2] See Almond and Mazumder (2013) for an inventory.

behavior response.[3] Our strategy adds to this discussion by using exposure to heat waves as a source of variation. Given the idiosyncrasy of the occurrence of a temperature shock, we argue that prenatal exposure to heat waves is more likely to be free of the endogeneity issues that plague these previous works.

The rest of the paper is structured as follows. In section 2, we provide background information on the relationship between heat stress and offspring outcomes. In sections 3 and 4, we describe our data and empirical strategy, respectively. In section 5, we present our empirical findings, including robustness checks and section 6 includes an exploration of potential long-run impacts on human capital accumulation. Section 7 concludes.

2. Background on Heat-Stress and Endowments

Exposure to high temperatures is one of the most encountered physical stressful events. Medical literature indicates that prenatal heat stress increases mother's levels of cortisol, a hormone that plays a critical role in fetal health and the regulation of the psychomotor development (Davis and Sandman 2010; Wadhwa et al. 1993).[4] An early study by Vaha-Eskeli et al. (1991) investigates the effect of moderate heat stress on levels of cortisol in three groups of women: 1) non-pregnant women, (2) women 13-14 weeks pregnant, and (3) women 36-37 weeks pregnant. Blood samples were taken every 5–10 minutes during a resting period followed by the heat stress intervention. Although this study uses a relatively small sample, the authors found that exposure to moderate heat stress increased significantly cortisol levels in pregnant women. While this study does not examine offspring outcomes, it does suggest that changes in cortisol levels could be an important mediator. This evidence is important in view of the growing consensus that prenatal exposure to increased cortisol levels negatively impacts offspring outcomes. Indeed, a set of recent studies have found that exposure to high increased levels of cortisol is associated with impaired brain development at three and eight months, and with worse health outcomes (Aizer, Stroud, and Buka 2012; Huizink et al. 2003).

Considering this, it has been hypothesized that prenatal heat stress can have adverse consequences on child outcomes. Randomized studies based on animals have established a strong link between *in utero* exposure to extreme hot temperatures and poor offspring outcomes. These works generally exogenously expose pregnant animals to high temperatures. Examples include Shiota and Kayamura (1989) who exposed mice to high temperatures during pregnancy and observed retardation in brain growth of offspring. Strong, Silva, Cheng, and Eicher (2015) likewise exposed pregnant cows to hot temperatures and found that the offspring of exposed cows exhibited poorer health outcomes, including damages in immune system.

As these studies show that heat stress during the prenatal period results in diminished offspring outcomes, they are keys to extrapolate findings based on animal experiments to humans. This supports evidence from non-randomized studies that exposure to extreme hot temperatures during pregnancy is associated with poor infant outcomes. Much of this evidence becomes from epidemiological literature. In general, this literature finds that exposure to higher temperatures is associated with increased risk of prematurity and low birth weight.[5] But these studies suffer from problems of endogeneity as they are based on cross-sectional or time series comparisons. Surprisingly, the most convincing evidence comes from works in economics. For

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[3] Some studies using twin-fixed effects have overcome this problem. However, those works based on comparisons of non-twin siblings must deal with the problems mentioned above.

[4] There are other potential mechanisms through which extreme hot temperatures may affect initial endowments, including increases in disease transmission like malaria. It has been well documented that prenatal exposure to malaria is associated with poorer birth outcomes (e.g, Sarr et al. 2006). However, we believed that such mechanism is likely to be less prominent since the incidence of malaria is not high in Colombia. While this potential mechanism is not emphasized through article, we do not rule out the possibility that it plays a role.

[5] A full review of the epidemiological literature can be found in Strand, Barnett, and Tong (2011).

instance, Deschenes, Greenstone, and Guryan (2009) exploit plausible exogenous variation in temperature within counties in U.S and find that prenatal heat stress during second trimester negatively affects birth-weight. Other studies using a similar approach find also negative impacts on APGAR scores and prematurity (Andalón et al. 2014). In general, this body of evidence suggests that prenatal heat stress could have adverse consequences on child endowments.

3. Data

Our analysis is based on children who are under five years of age with at least a sibling. Below, we describe the weather, investment, and supplementary data that we will analyze. Investment outcomes data are available for cohorts born 1990–2010. To identify exposure to heat waves during pregnancy, these data are matched to the weather measures based on the date of birth and the mother's municipality of residence. Summary statistics of these data are presented in Table 1.

3.1. *Weather Dataset*

We have built a series for temperature and precipitation using data from the Terrestrial Air Temperature and Terrestrial Precipitation: 1900–2010 Gridded Monthly Time Series, version 3.02, respectively (Matsuura and Willmott 2012). This dataset provides worldwide estimates for weather conditions at the 0.5 *x* 0.5 degree latitude/longitude grid.[6] Using an interpolation algorithm, Matsuura and Willmott (2012) computes values for each grid node from several nearby weather stations. Since some years did not have weather stations over the entire period, the data for missing years are imputed using a meteorological model. To minimize any potential bias from this measurement error, we focus on the period 1970-2010, as most of the weather stations were established in Colombia from 1970 and onwards. We use a strategy similar to Rocha and Soares (2015) to construct a municipality-by-month of weather panel. To start, we compute the centroid for each of the 1,120 municipalities in Colombia. Then, using the centroid, we located the four closest nodes to build a monthly series of temperature and precipitation as the weighted average of estimates related to these four nodes. As weights, we use the inverse of the distance to each node. The mean per municipality per month of temperature in our sample is 21.5 ºC, with a standard deviation of 4.7 ºC.

Using this consolidated dataset, we define a heat wave for a given month as temperature above the 90^{th} percentile of distribution for that calendar month within the municipality. Since we are not comparing municipalities, the "extreme" hot temperature should not be taken in an absolute sense. These are simply extreme high temperature months for each municipality within the given time frame. We also investigate the effects of less severe heat waves by defining heat wave as temperature above 85^{th}, 80^{th}, and 75^{th} percentiles.

Prenatal exposure to heat waves through pregnancy is measured by *first trimester*, *second trimester,* and *third trimester*. If, for example, a child was born on October, then *first trimester* is calculated as the number of extreme high temperature months that occurred in their municipality of birth during the months of February, March and April. Naturally, the s*econd trimester* is computed by the number of extreme high temperature months that occurred in their municipality of birth during the months of May, June, and July; and *third trimester* is computed using these criteria during the months of August, September, and October.

3.2. *Main Outcomes*

Our empirical analysis uses the 1995, 2000, 2005 and 2010 waves of the Demographic and Health Survey (DHS) of Colombia, a nationally representative survey of women ages 15 to 49. The DHS contains detailed

[6] 0.5 degree correspond to 56 kilometers.

information on early-life health investments for all children under five. For our analysis, we pooled these DHS waves into one dataset. We restricted the sample to mothers with at least two children given that we used family fixed effects models. We also focus on children who were more than 12 months old at time of the survey. Our basic sample consists of 8,949 children with at least one sibling. We use the municipality of residence as a proxy for child's municipality of birth. This is a reasonable proxy given the low migration rates of infants.

Our health investments variables include vaccinations, and breastfeeding. Available measures of vaccination reported consistently across the four waves of the DHS include: polio, DPT (diphtheria, pertussis and tetanus combination), and measles. In Colombia, the recommend vaccination schedule is: polio at two months, four months, and six months; DPT at two months, four months, and six months; measles at 11 months. Our analysis investigates the effect of prenatal heat on the likelihood of being vaccinated for specific diseases. In terms of breastfeeding, we use a dummy variable that equals to one if the child was breastfed for more than six months. This is the minimum length of breastfeeding recommended by the World Health Organization. In the 2005 DHS, breastfeeding duration is only recorded for the youngest child born to a surveyed mother. Therefore, we exclude children from the 2005 DHS for the breastfeeding analysis.

3.3. *Other Data*

As a complementary analysis, we use the birth certificate microdata for the period 1998-2010 from the Colombian Department of Statistics (DANE). We obtained these administrative data for all the municipalities in Colombia- approximately 8 million birth records. This register provides date of delivery, information on gestation length, weight, and APGAR scores. In Colombia, there are between 400,000 and 700,000 births per year.[7] Using this information, we construct a municipality-by-month of birth data set for the 1998-2010 period. The municipality of reference in this panel is that where the mother lives at birth. Our outcomes of interest are rate of low 5 minute APGAR (<8), rate of very low birth-weight (≤1,500 gr.), rate of low birth-weight (≤2,500 gr.), rate of birth via Caesarian section and rate of prematurity (less that 37 weeks of gestation).[8]

For further analysis, we also use microdata from the 2005 demographic census (the most recent available). The Integrated Public Use Microdata Series (IPUMS) provides a one percent sample. Although the census does not collected information on parental investments, we can assess whether selective migration may drive our main results. Using these data, we also estimate the long-term impacts of prenatal exposure to heat waves. The census does not have any measure of earnings, but there is information on educational attainment. Educational attainment is particularly interesting, as it is an important determinant of other later-life outcomes, including earnings, health and productivity (Cutler and Lleras-Muney 2010; Oreopoulos 2006). Thus, we investigate whether prenatal heat waves affect total years of schooling for adults aged 20-36.

Finally, we use other data sources for supplementary analysis. To assess whether our main results may be driven by changes in the local economic activity, we collected data on: *i*) municipality-year level information on local public revenue and spending collected by the Economics Research Center at Andes University for

[7] Since there is no unique mother identifier in the data, subsequent births by the same mother cannot be identified. This precludes the use of the sibling-fixed effects estimator.
[8] APGAR score is a clinical test that is given to the newborn in which five parameters are assessed. The parameters evaluated are muscle tone, respiratory effort, heart rate, reflexes and skin color. The test provides a total score between 0 and 10, where a higher score means healthier.

the period 1993-2010; *ii*) *departmento*-year level data on Gross Domestic Product (GDP) and Agricultural production (available for the period 1990-2010) from the DANE.[9]

3.4. *Variation in Prenatal Heat Stress Within Families*

An important concern about the sibling analysis is that siblings may experience "too similar" prenatal exposure to extreme hot temperatures. This may weaken the within-sibling relation between parental investments and prenatal heat stress. However, this argument has little empirical support. Prenatal exposure to heat waves varies widely across children in our sample. The standard deviation in the number of months exposed to hot temperatures during pregnancy is 1.58 (relative to a mean of 0.94). More importantly, mother fixed-effects explain only about 48 percent of the variation in the number of months exposed to heat waves while *in utero*, leaving a fair amount of within-sibling variation. This wide within-sibling variation is the basis of our identification strategy.

4. Empirical Strategy

Equation (1) relates each parental investment, y, of the child (*i*) born from mother (*j)* in municipality (*k)* to the three measures of prenatal heat waves discussed above:

$$y_{ijktm} = \alpha + \beta_1(1sttrimester)_{ijktm} + \beta_2(2ndtrimester)_{ijktm} + \beta_3(3rdtrimester)_{ijktm} + \delta' X_{ijktm} + \eta_j + \lambda_t + \mu_m + \xi_{ijktm} \quad (1)$$

where the vector X_{ijktm} includes indicators for child's gender, birth order, age in months, and municipal-rainfall for each trimester. λ_t, and μ_m are fixed effects for year of birth and month of birth, respectively. Because η_j is included on the right-hand side of the equation, it is used only within-sibling variation to identify the parameters β_1 through β_3.

Model (1) essentially uses sibling differences in prenatal exposure to extreme hot temperatures, the timing of which is plausibly exogenous, give the unpredictability of a temperature shock, to identify prenatal heat stress impacts. Thus, our strategy compares parental investments of children prenatally exposed to greater extreme hot temperature months against the parental investments for siblings exposed to less extreme hot temperature months. The reason why one of them ended up with a greater exposure and the other one did not can be, for all practical purposes, considered as random. Given the evidence of previous studies that heat stress during pregnancy has negative consequences on initial endowments, positives values for β_1, β_2, and β_3 are interpreted as compensatory parental responses and negative values are interpreted as reinforcing responses.

Using this empirical approach, we are able to identify the causal impact of prenatal extreme hot temperature on parental responses. A potential problem pervading our analysis is related to recent evidence that parents may be changing fertility decisions based on temperature around the time of conception. Barreca, Deschenes, and Guldi (2015) convincingly show that parents are likely to postpone conception by one month in response to additional extreme high temperature. To the extent that this is important and that these parents may differ in ways that could affect parental inputs, between-family estimates of the effect of heat stress during first trimester may be biased. Our approach deals with this issue as it relies on within-family comparisons, thereby controlling any time-invariant family qualities. The use of this strategy would be biased if the specific-shift in the timing of conception is directly related to future family postnatal investments. There is no reason to believe that this is plausible. In addition, we provide a variety of evidence that our

[9] *Departamento* is a first-order administrative unit similar to U.S States. In Colombia, there are 33 *departamento.*

results are unlikely to be driven by time series correlation in temperature, selective fertility, migration, or changes in local economic activity.

5. Results

5.1. *Main Results*

Our main results are presented in Table 2. Columns (1)-(4) look at vaccination during infancy. We use dummy variables indicating whether the child has the recommend vaccination doses for specific diseases. Column (4) uses a dummy variable that equals one if the child has all recommend vaccination doses. The results for breastfeeding are presented in columns (5).

The results from (1)-(4) show that exposure to heat waves during second trimester significantly increases the likelihood of being vaccinated. The magnitudes of the effects vary depending on the vaccination. One additional month of exposure to heat waves during the second trimester increases the probability of receiving the recommend vaccination schedule for polio, DPT, and measles by 2, 3, and 1.5 percentage points, respectively. In column (5), we find that exposure to prenatal heat stress during second trimester is significantly associated with increases in probability of having been breastfed for more than six months (point estimate of 0.03).

Overall, the evidence suggests that prenatal heat stress increases health investments. One way to assess the size of the effects is to compare them to the impacts of early-life interventions. For example, Attanasio et al. (2005) show that *Familias en Accion* (FA), a conditional cash transfer program in Colombia, increases the probability of DPT vaccination by 9 percentage points. This shows that the estimated effect of second trimester exposure on DPT vaccination is on third of the effect of the FA program. In other words, the child from a mother who was exposed to three extreme high temperature months during the second trimester would have a similar probability of receiving DPT vaccination as a child of a mother enrolled in the FA program.

5.2. *Heterogeneity by severity of intensity*

Our baseline specifications estimate the impacts of prenatal exposure to very extreme hot temperatures. A natural extension is to assess the presence of heterogeneous effects with respect to the severity of the shock. Table 3 explores this question by using measures of prenatal exposure that define heat waves as temperature above 85^{th}, 80^{th}, and 75^{th} of distribution. In general, we find in fact that exposure to less extreme hot temperatures has significant smaller effects. For example, the marginal effect of exposure during second trimester ranges on the likelihood of total vaccination ranges from 3.5 percentage points in the baseline estimate to 1.6 percentage points in specification that uses the least extreme measure of heat wave. This analysis highlights the usefulness of an intensity-specific analysis when assessing the effects of environmental shocks *in utero*.

5.3. *Potential Mechanisms and Robustness Checks*

Next, we explore potential mechanism by which maternal heat stress affects parental investments. The results from this section suggest that variations in child endowments is a plausible explanation to our results. While the evidence is supportive of this idea, alternative interpretations may be also consistent with the patterns in parental investments. As we shall see, such alternative hypothesis have little empirical support.

5.3.1 Heat stress and child endowments

Studies based largely on animal experiments suggest that exogenous exposure to heat stress *in utero* negatively affects offspring endowments. This and discussions in economics that returns to child investments depend on initial endowments suggest that variations in birth endowments could be an important mediator between maternal heat stress and parental investments. While there is extensive literature documenting that prenatal heat stress has adverse consequences on fetal health (see, for example, Deschenes, Greenstone, and Guryan (2009)), we also test for the relationship using birth certificate data for the period 1998-2010. The results are presented in Table 4. We weight observations by the number of births per month in the municipality.

Panel A uses a specification that adjusts only for the baby's sex, for municipality-rainfall in each trimester and for municipality of residence at birth, year of birth and month of birth fixed effects. We find a positive and significant effect of prenatal exposure to heat stress during first trimester on very low birth weight. Increasing the number of extreme high temperature months by 1 increases the probability of very low birth weight by 0.009 percentage points (*P*-value=0.052). Compared to the mean of 0.8 percent, the effect is 1.1 percent. We also find that prenatal heat stress during second trimester has a positive and large effect on the likelihood of having a low APGAR score. One additional month exposed during second trimester increases the incidence of low 5 minute APGAR by 0.98 percentage points. Relative to the mean low 5 minute APGAR rate of 2.3 percent, the effect is substantial at 40 percent. Almond, Chay, and Lee (2005) show that 5 minute APGAR may be a more reliable measure of fetal health than birth weight.

The remaining columns examine the effect on other proxies for fetal health. In column (4) we show that an additional heat wave in the second trimester increases the probability of having a caesarian section by 0.16 percent points (*p*-value =0.04). We consider that this variable potentially reflects the presence of problems at birth, which may be correlated with an increased risk of poor infant health. The specific timing of the effect is consistent with Currie and Rossin-Slater (2013) who find that exposure to stress induced by an extreme weather event during the second trimester increases the probability of having a caesarian section in U.S. In column (5) we also find that exposure to prenatal heat in the third trimester leads to preterm birth.

Panel B corresponds to specifications that include maternal characteristics as control variables. The estimated coefficients are insensitive to adding such additional variables. In general, the estimates are significant and imply that prenatal exposure to heat waves is associated with poorer health at birth. Furthermore, in many cases, their precision improves. This provides reassuring evidence on the validity of the empirical approach.

Overall, the findings support the notion that heat waves can have adverse consequences on the infant health, confirming the evidence from prior studies. It is important to recognize that this analysis may underestimate the impact of heat stress, as we do not use other more direct measures of infant health. For example, Currie and Rossin-Slater (2013) show convincingly that prenatal stress induced by extreme weather events has a substantial larger effect on the probability of complications of labor and delivery, and of abnormal conditions such as meconium aspiration syndrome. In view of this evidence and that these variables could be more direct proxies for health at birth, our estimates can be interpreted as lower bounds of the effect of maternal heat stress on infant health.

5.3.2 Migration

Given that we use the municipality of residence as a proxy for child's municipality of birth, a bias could drive our results if municipality-migration is related to extreme hot temperatures. It is hard to argue that this is the case since we have used temporary variations in temperature and they are unable to cause disruption of physical infrastructure (unlike others weather events such as storms). To asses this more formally, we have examined the 2005 census and analyzed differences in prenatal heat waves between migrant and non-migrant children. In Table 5 we regress prenatal exposure to heat waves on a dummy variable that equals 1 if the child was born in the survey municipality. Consistent with the view that heat waves are unlikely to be related to migration, we find no differences in prenatal exposure to extreme hot temperatures between migrant and non-migrant children.

Still, the use of municipality of residence as a proxy for municipality of birth most likely introduces a random measurement error that attenuates our estimates. To investigate the magnitude of this potential bias, in Table 6 we estimate the investment regressions based on a sample that includes only mothers with children who were born in the municipality of residence. The results are qualitatively similar to our baseline estimates. While in general the estimated coefficients of second trimester exposure are larger in magnitude, they are very similar to those of the baseline estimates. Collectively, these findings are consistent with the presence of a random measurement error and suggest that the resulting attenuation bias in our sample is small.

5.3.3. Subsequent fertility

Some studies argue that child endowments can affect future fertility decisions. This would be a potential channel explaining the link between heat stress, initial endowments and parental investments. The seminal study by Becker and Tomes (1976) suggests ambiguous predictions on the direction of how variations in child endowments may affect future fertility. On the one hand, if less healthy children increase the cost of child quantity, then it would lead to a reduction in fertility. Alternatively, if returns to child quality are lower in less endowed children, then this would increase fertility in response to the higher shadow price of child quality. However, we are unable to find any significant effect of heat waves on fertility. We do this in Table 7 by checking whether prenatal heat stress affects the quantity and spacing of children. The estimates are small and tightly bound around zero, suggesting that having a child who was prenatally exposed to heat waves did not alter subsequent fertility decisions significantly.

5.3.4. Other hypothesis

Perhaps an obvious objection to our interpretation of the main results comes from recent evidence that high temperatures shocks lead to economic downturns (Dell, Jones, and Olken 2012). Therefore, one may argue that the patterns in parental investments are in fact not so much determined by child endowment shifts, but by parents' reactions to reductions in the cost of opportunity, given that the inputs we have used are time-intensive. This hypothesis is somewhat consistent with Miller and Urdinola (2010) who show that time-intensive investments are higher during economic downturns. Yet, for this alternative interpretation to make sense, agricultural sector should be an important sector in the Colombian economy. This does not seem to be the case. Indeed, the agricultural value-added only accounts for 11 percent of GDP across the 1990-2010 period, which contrasts with countries like Uganda where agriculture importance ranges from 30 to 60 percent of GDP. Furthermore, the available evidence indicates that higher temperature leads to economic downturns only in poor countries. Even if temperature shock lead to economic downturn, it is hard to think of reasons why this would explain significant effects on parental investments in urban children since such economic shocks would be presumably important in rural areas. In fact, we find little evidence of differential impacts between rural and urban children.[10]

In any case, we can directly investigate this alternative hypothesis by estimating the relationship between heat waves and production, using *departmento*-year level data on GDP and agricultural production

[10] These analyses are available upon author request.

for the period 1990-2010, and municipality-level data on local public finance for years 1993 through 2010. We use data on public finance as proxies for local economic activity. The variable independents of interest are the number of extreme high temperature months that occurred in the *departamento*/municipality in a given year, along with a one-year lag. The results are presented in Table 8, with dependent variables shown in the first column of each row. Considering the discussion above, it is not surprising to find insignificant estimates on these regressions. Moreover, the estimated coefficients are very small in magnitude. We take these results as evidence that our main findings are in fact not driven by changes in local economic activity.

Other alternative hypothesis is that heat waves this month may be correlated with heat waves next months. If so, our estimates may not represent the effects of heat waves while *in utero*. While this is a reasonable hypothesis, we can test it by including in the same regressions the variables of heat exposure after birth. We do this in Table 9. The coefficients associated with heat stress *in utero* during second trimester remain virtually identical, casting doubt on this alternative explanation.

One could argue that was not just child endowment shifts that affect parental investments, but also reductions in time allocated to labor to minimize the potential health impacts of warmer temperatures. This idea is made more plausible in view of evidence from Graff Zivin and Neidell (2014), who find a moderate short-run (within few weeks after the shock) decline in time allocated to labor at high temperature. This alternative hypothesis may explain why parents increase health investments, as vaccination and breastfeeding inputs are made early in life. However, the evidence from Table 2 that exposure during the third trimester does not affect parental investments weights against this alternative interpretation, as one would expected to observe an effect of exposure around the time of birth. Note also that, to the extent that this explanation is important, we should see changes in our estimates when controlling for heat waves after birth. We do not. Although we cannot completely rule out this possibility, the evidence suggests that it is unlikely to be the main mechanism driving the patterns in parental investments.

5.3.5. Further robustness checks

We conduct additional robustness checks.[11] First, we examine the relationship between prenatal heat stress and parental investments by using specifications that control for municipality-specific linear time trends. In general, the use of this more demanding specification produces estimated coefficients of the second trimester exposure that are very similar and that remain statistically significant. Second, we exclude twin children given that prenatal exposure between them does not vary. Our results are broadly similar. Finally, we also assess whether there are heterogeneous effects by child's sex, rural/urban location, and mother's education. We then present estimates that interact second trimester exposure with these characteristics. We find differential impacts that are statistically significant only in a few cases. For instance, the compensating investment behavior in terms of breastfeeding is more pronounced in boys than girls. Still, there are no significant differences between boys and girls in vaccinations. We conclude that there is little evidence of a consistent interaction between prenatal heat exposure and these characteristics.

6. Long-Term Effects on Human Capital Accumulation

We also explore whether there are long-term impacts of exposure to extreme hot temperatures on the accumulation of human capital. If parental health inputs are important enough in the production of child quality, then the prenatal temperature shock may be completely remedied. To explore this question, we use data from 2005 census and estimate a specification similar to Eq. (1), but in this case we use total years of schooling for cohorts born 1970–1986 (ages 20-36 at time of survey) as a dependent variable. The census

[11] Given space constraints, we do not present the results for these robustness exercises, but they are available upon author request.

only keeps information on the sibling composition of those individuals who co-reside with their relatives. As adults are less likely to live with their parents than children, we do not include sibling-fixed effects. In practice, we include a robust set of municipality of birth, year of birth and month of birth fixed effects.

In Table 10, the results indicate that exposure during second trimester of pregnancy to heat waves is associated with lower levels of schooling. The effect in magnitude is small (0.3 percent relative to the mean). Column (3) uses a specification that interacts second trimester with female. While the effect appears to be stronger for men, this heterogeneity is not statistically significant. The results from columns (4)-(6) show that the estimated coefficient is robust to controlling for exposure to heat waves after birth. Overall, in this section, we provide evidence that the effects of prenatal heat waves can last into adulthood, suggesting that compensatory health investments during infancy are not sufficient to remedy the initial health insult.

7. Conclusion

In this paper we estimate the impacts of *in utero* exposure to heat waves on parental investments using Colombian data. We find that prenatal exposure to heat waves is associated with more postnatal health investments. A variety of evidence is presented in favor of the interpretation that this parental behavior reflects compensating responses to shifts in children's endowments. We interpret these findings as evidence highly consistent with the model of intrahousehold resource allocation from Yi et al (2015). In particular a possible interpretation is that under substitutability between health and investment in health, endowment shifts induced by prenatal heat stress would increase the returns to child health quality. As a result, parents responded by devoting more resources in health.

These results relate to a growing literature in economics that documents long-term effects of exposure *in utero* to environmental shocks. The findings in this paper are consistent with previous studies indicating that family investments respond to child endowments. One implication is that reduced-form estimates of the effect of environmental conditions *in utero* on later life outcomes do not necessarily represent a biological effect. Therefore, caution is necessary when interpret estimates from such studies.

Our findings have important policy implications. Climatic projections indicate that the climate's earth will become hotter in the coming century, which would make more frequent the incidence of extreme weather events. The long-term effects of such extreme weather events on human capital accumulation several decades later should be factored into cost-benefit analyses of climate change mitigation policies. The evidence that the initial shock is not completely remedied by parental investments provides additional justification for interventions that shield pregnant women from the consequences of temporary environmental shocks.

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Tables

Table 1. Descriptive statistics, Demography Health Survey (1995, 2000, 2005 and 2010 rounds)

	Mean	Standard deviation
Complete schedule of vaccination (Polio, DPT and Measles doses)	0.60	0.48
Complete schedule of Polio vaccination	0.72	0.44
Complete schedule of DPT vaccination	0.80	0.40
Measles vaccination	0.83	0.37
Breastfed for more than six months	0.68	0.46
Child is male	0.51	0.50
Child's age in months	35.50	1.45
First born	0.21	0.41

Note. Survey weights are used.

Table 2. Effects of Heat Waves *In Utero* on Parental Investments

	Health investments				
	Vaccinations				
	Polio	DPT	Measles	Total vaccination	Breastfed for more than six months
	(1)	(2)	(3)	(4)	(5)
1st Trimester	-0.000	-0.005	-0.010	-0.001	0.006
	[0.011]	[0.011]	[0.008]	[0.011]	[0.016]
2nd Trimester	0.022	0.029	0.015	0.035	0.031
	[0.009]**	[0.010]***	[0.009]*	[0.012]***	[0.015]**
3rd Trimester	0.014	-0.003	-0.008	-0.004	0.002
	[0.010]	[0.008]	[0.009]	[0.009]	[0.015]
N	8,949	8,949	8,949	8,949	5,932

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. All regressions are based on the mother-effects fixed estimator, and include as controls dummies for age in months, precipitation in each trimester, dummies for year of birth, dummies for month of birth, and child's sex and birth order.

Table 3. Effects of Heat Waves *In Utero* on Parental Investments (Heterogeneity by severity of intensity)

	Temperature above:			
	90th percentile (1)	*85th percentile* (2)	*80th percentile* (3)	*75th percentile* (4)
	Panel A: Dependent Variable is Polio vaccination			
2nd Trimester heat exposure	0.022	0.025	0.016	0.019
	[0.009]**	[0.008]***	[0.007]**	[0.007]**
N	8,949	8,949	8,949	8,949
	Panel B: Dependent Variable is DPT vaccination			
2nd Trimester heat exposure	0.029	0.018	0.015	0.010
	[0.010]***	[0.008]**	[0.006]**	[0.005]*
N	8,949	8,949	8,949	8,949
	Panel C: Dependent Variable is Measles vaccination			
2nd Trimester heat exposure	0.015	0.014	0.009	0.005
	[0.009]*	[0.007]**	[0.006]	[0.006]
N	8,949	8,949	8,949	8,949
	Panel D: Dependent Variable is Total vaccinations			
2nd Trimester heat exposure	0.035	0.027	0.019	0.016
	[0.012]***	[0.011]**	[0.009]**	[0.007]**
N	8,949	8,949	8,949	8,949
	Panel E: Dependent Variable is Breastfed for more than six months			
2nd Trimester heat exposure	0.031	0.017	0.009	0.005
	[0.015]**	[0.012]	[0.010]	[0.009]
N	5,932	5,932	5,932	5,932

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. Column (1) produces baseline results. Columns (2) through (4) report estimates by using alternative definitions of prenatal heat waves.

Table 4. Effects of Heat Waves *In Utero* on Birth Outcomes

	Rate of very low birth weight (1)	Rate of low birth weight (2)	Rate of low 5 minute APGAR (3)	Rate of C-Section (4)	Rate of preterm birth (5)
	Panel A: Baseline specification				
1st Trimester in utero	0.0099	0.0004	-0.200	0.1161	0.0036
	[0.0050]**	[0.0258]	[0.441]	[0.1271]	[0.0405]
2nd Trimester in utero	-0.0060	-0.0008	0.9880	0.1662	-0.0776
	[0.0044]	[0.0201]	[0.5770]*	[0.0839]**	[0.0589]
3rd Trimester in utero	0.0010	0.0131	0.3370	0.03762	0.0580
	[0.0046]	[0.0223]	[0.3120]	[0.1140]	[0.0332]*
	Panel B: Controlling for maternal characteristics				
1st Trimester in utero	0.0099	-0.0009	-0.2050	0.1321	0.0044
	[0.0049]**	[0.0255]	[0.4461]	[0.1272]	[0.0401]
2ndTrimester in utero	-0.0061	-0.0024	0.9890	0.1711	-0.0792
	[0.0045]	[0.0196]	[0.5781]*	[0.0836]**	[0.0591]
3rd Trimester in utero	0.0010	0.0117	0.3311	0.0508	0.0585
	[0.0046]	[0.0218]	[0.3091]	[0.1161]	[0.0328]*
Mean of dependent variable	0.82	7.31	2.32	30.23	14.15
N	168,692	168,692	167,800	169,113	168,743

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. Panel A is a specification that controls for municipality of birth, year of birth, and month of birth fixed effects, and for precipitation in each trimester, and baby's sex. In addition, Panel B includes dummy for mother age under 20 years, dummy for mother age over 45 years, dummy for mother's education (some college), dummy for mother's marital status (married).

Table 5. Heat Waves *In Utero* between migrant and non-migrant children

	Number of prenatal heat waves during:		
	1st trimester	2nd trimester	3rd trimester
	(1)	(2)	(3)
Child was born in the survey municipality	0.021	0.001	-0.012
	[0.0158]	[0.014]	[0.016]
N	1,222,311	1,222,311	1,222,311

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. All regressions are based on the mother-effects fixed estimator, and include controls for precipitation in each trimester, dummies for municipality of birth, dummies for year of birth, dummies for month of birth, and child's sex and age.

Table 6. Effects of Heat Waves *In Utero* on Parental Investments (Excluding migrant families)

	Health investments				
	Vaccinations				
	Polio	DPT	Measles	Total Vaccination	Breastfed for more than six months
	(1)	(2)	(3)	(4)	(5)
	Panel A: Baseline estimates				
1st Trimester	-0.000	-0.005	-0.010	0.001	0.006
	[0.011]	[0.011]	[0.008]	[0.013]	[0.016]
2nd Trimester	0.022	0.029	0.015	0.035	0.031
	[0.010]**	[0.010]***	[0.009]*	[0.012]***	[0.015]**
3rd Trimester	0.014	-0.003	-0.008	-0.004	-0.002
	[0.010]	[0.007]	[0.009]	[0.009]	[0.015]
N	8,949	8,949	8,949	8,949	5,932
	Panel B: Excluding migrant families				
1st Trimester	0.000	-0.008	-0.006	0.003	0.010
	[0.012]	[0.011]	[0.008]	[0.013]	[0.018]
2nd Trimester	0.029	0.039	0.014	0.043	0.040
	[0.009]***	[0.010]***	[0.010]	[0.014]***	[0.015]***
3rd Trimester	0.018	-0.009	-0.008	-0.005	-0.008
	[0.012]	[0.009]	[0.011]	[0.011]	[0.014]
N	7,150	7,150	7,150	7,150	4,714

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. Panel A produces baseline results. Panel B presents results based on a sample of children who were born in the municipality of residence.

Table 7. Effects of Heat Waves *In Utero* on Quantity and Spacing of Births

	Subsequent births (1)	Succeeding birth interval (2)
1st Trimester	-0.000	-0.600
	[0.004]	[0.366]
2nd Trimester	0.001	0.335
	[0.005]	[0.39]
3rd Trimester	0.002	0.484
	[0.005]	[0.360]
N	8,949	4,923

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. All regressions are based on the mother-effects fixed estimator, and include controls for mother's age at birth, precipitation in each trimester, dummies for year of birth, dummies for month of birth, and child's sex and birth order.

Table 8. Relationship between Heat Waves and Economic Activity

	$(\text{Heat waves})_t$		$(\text{Heat waves})_{t-1}$		
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	N
Agricultural production	-0.001	[0.010]	0.005	[0.008]	640
GDP	0.005	[0.004]	0.004	[0.003]	660
Total Income (Indirect+ direct taxes)	-0.002	[0.004]	-0.003	[0.003]	17,257
Capital Income	-0.005	[0.006]	0.002	[0.006]	16,304
Transfer	0.005	[0.004]	0.000	[0.007]	16,791
Total Spending	-0.001	[0.004]	-0.003	[0.004]	17,316
Investment Spending	-0.004	[0.005]	0.002	[0.007]	11,676
Operational Spending	0.000	[0.002]	-0.007	[0.005]	17,236
Housing Spending	-0.001	[0.017]	-0.010	[0.020]	10,211
Education Spending	-0.008	[0.012]	0.000	[0.010]	11,662
Health Spending	-0.001	[0.007]	0.006	[0.007]	11,648

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the *departamento* level. Coefficients in each row are from a different regression. Regressions for agricultural production and GDP use data at *departamento* level and include *departamento* and year fixed effects, and control for precipitation and *departamento*-specific time trends. Regressions on local public finance use data at municipality level and include municipality and year fixed effects, and controls for precipitation and *departamento*-specific time trends.

Table 9. Effects of Heat Waves *In Utero* on Parental Investments (controlling for heat waves after birth)

		Controlling for heat waves:				
	Baseline	*1 trimester after birth*	*2 trimester after birth*	*3 trimester after birth*	*4 trimester after birth*	*5 trimester after birth*
	(1)	(2)	(3)	(4)	(5)	(6)
		Panel A: Dependent Variable is Polio vaccination				
2nd Trimester heat exposure	0.022	0.022	0.024	0.022	0.022	0.022
	[0.009]**	[0.009]**	[0.009]***	[0.009]**	[0.009]**	[0.009]**
		Panel B: Dependent Variable is DPT vaccination				
2nd Trimester heat exposure	0.029	0.029	0.029	0.028	0.028	0.028
	[0.010]***	[0.010]***	[0.010]***	[0.010]***	[0.010]***	[0.010]***
		Panel C: Dependent Variable is Measles vaccination				
2nd Trimester heat exposure	0.015	0.015	0.016	0.016	0.017	0.016
	[0.009]*	[0.009]*	[0.010]*	[0.010*]	[0.010]*	[0.009]*
		Panel D: Dependent Variable is Total vaccinations				
2nd Trimester heat exposure	0.035	0.035	0.036	0.034	0.034	0.034
	[0.012]***	[0.012]***	[0.012]***	[0.012]***	[0.012]***	[0.012]***
		Panel E: Dependent Variable is Breastfed for more than six months				
2nd Trimester heat exposure	0.031	0.031	0.031	0.028	0.028	0.028
	[0.015]**	[0.015]**	[0.014]**	[0.014]*	[0.014]*	[0.014]*

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. Column (1) produces baseline results. Columns (2) through (6) report estimates controlling for heat waves after birth.

Table 10. Effects of Heat Waves *In Utero* on Total Schooling

	(1)	(2)	(3)	(4)	(5)	(6)
1st Trimester	0.007			0.007	0.005	0.005
	[0.013]			[0.013]	[0.014]	[0.014]
2nd Trimester	-0.030	-0.036	-0.053	-0.030	-0.031	-0.033
	[0.014]**	[0.014]**	[0.015]***	[0.014]**	[0.014]**	[0.014]**
3rd Trimester	-0.026			-0.022	-0.020	-0.021
	[0.030]			[0.029]	[0.029]	[0.029]
2nd Trimester x Female			0.033			
			[0.021]			
1st Trimester after birth				-0.014	-0.008	-0.006
				[0.017]	[0.017]	[0.017]
2nd Trimester after birth					-0.023	-0.016
					[0.022]	[0.020]
3rd Trimester after birth						-0.025
						[0.016]
N	9,092,354	9,092,354	9,092,354	9,092,354	9,092,354	9,092,354

Notes. Robust standard errors in brackets (***p < 0.01, **p < 0.05, *p < 0.1) are clustered at the municipality level. Dependent variable is years of education (Ages 20-36). The regressions contain municipality of birth, year of birth and month of birth fixed effects, and controls for age and sex.