HEAT WAVES AT CONCEPTION AND LATER LIFE OUTCOMES

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Abstract

A large body of research has recently shown that early life or in utero shocks, especially climatic shocks, may affect long-run human capital outcomes. Most of these effects are assumed to be biological – including poor nutrition during critical windows of fetal development, or through increased maternal stress. However, in addition to these biological effects, climatic conditions at the time of conception may also cause changes in parental behavior, not only affecting the mix of parents who conceive, but also the characteristics of the children once born. This paper explores whether increases in ambient temperature at the time of conception, while in utero, or after birth cause better educational and health outcomes as adults. Using Census and DHS data from sub-Saharan Africa, we show that individuals conceived during heat waves have higher educational attainment and literacy, fewer disabilities, and lower child mortality. However, we find no effect of temperature at other times in utero. We then explore the biological and behavioral

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mechanisms through which this effect may occur, including heat-induced changes in sexual behavior, differences in parental characteristics, and intensified fetal selection. We show that fetal selection is the most likely mechanism driving our result. We also show that heat waves changes the mix of conceiving women to be more educated, partly since heat-induced reductions in sexual activity are larger for uneducated women. Finally, we show that temperature spikes at conception reduce the number of unwanted children born nine months later, potentially increasing parental investments in these children once born.

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1 Introduction

Human capital is a fundamental component of labor productivity and income. For this reason, over the past several decades scholars and policy makers alike have emphasized the importance of education and health in reducing poverty in the developing world. A large number of studies explore the potential for early life environmental or nutritional shocks, especially in early childhood or in utero, to affect health, cognitive ability, educational attainment and other human capital outcomes.[1] While this literature has well established the link between early life shocks and infant or child outcomes, less is know about the long-run effects of these shocks. For example, Barker et al. (1990) famously argued that adverse nutritional shocks in utero affect the metabolic characteristics of the fetus which may lead to health problems later in life. But in practice, testing this hypothesis is difficult due to a range of competing factors, such as differential investment in less healthy children, fetal loss and natural selection, or behavior aimed at mitigating the effect of shocks.[2]

Recently, a considerable amount of attention has been placed on quantifying the effect of climate shocks on human capital outcomes given the interest in determining the "damage function" of climate change (Dell et al. 2014). This question is especially relevant given that most models of climate change not only predict an increased likelihood of extreme weather events, but also a disproportionate effect on the developing world – the area least able to mitigate the adverse effects of these shocks. Several studies have explored the effects of weather variables – such as rainfall, temperature, windstorms, and snowstorms – on a large number of dependent variables, including health outcomes. But most of these studies focus on the contemporaneous effects of temperature on health, and not on its long-run effect. For example, there is a small but growing literature examining the effect of temperature on mortality, cardiovascular conditions, or respiratory problems (Barreca 2012, Burgess et al. 2011, Curriero 2002, and Deschênes and Greenstone 2011).

[1] While this literature is much too voluminous to summarize here; see Almond and Currie (2011), Almond and Mazumder (2011), Bleakley (2007), Chen and Zhou (2007), Cutler et al. (2010), Deschênes et al. (2009), Gluckman et al. (2008), Maccini and Yang (2009), and Nikolov (2012) for recent examples.

[2] See Almond and Currie (2011) for an extensive discussion of these issues.

Only two studies examine the effect of temperature shocks in utero on short-run health outcomes: Deschênes et al. (2009) who find that heat waves during the third trimester lower birth weight in the US, and Kudamatsu et al. (2012) who find that temperature in utero increases infant mortality in malarious and drought-prone areas of sub-Saharan Africa. And no studies link temperature in utero or after birth to any long-run human capital outcome.[3]

Another gap in the literature is the fact that the reduced form effect of temperature at the time of conception on long-run outcomes is likely to be very different than at other times in utero. For example, heat waves may have heterogeneous effects on sexual behavior by education level or socioeconomic status, affecting the mix of couples which select into pregnancy. Fetal loss also frequently occurs soon after conception.[4] Therefore, the effect of natural selection may be more pronounced at this time than later in pregnancy when a negative shock may be more likely to scar the fetus than cull it. Finally, since women do not know they are pregnant at the time of conception, they may react differently to shocks compared with when the pregnancy is known.[5] As a result, the reduced-form effect of temperature on children conceived during heat waves is a mix of biological effects, behavioral effects from parents, and selection effects which are not present at other times in utero. To our knowledge, there are no studies investigating the link between temperature at conception and outcomes.

We fill these gaps by testing whether heat waves at conception, in utero, and immediately after birth causally affect long-run human capital outcomes. In particular, this paper estimates the monthly effect of temperature from 6 months before conception to 3 months after birth on educational attainment, literacy, and disability as adults

[3]In fact, the only study to our knowledge which links any early-life climate variable with long-run outcomes is Maccini and Yang (2009) who find a positive effect of rainfall in the year of birth on self-reported adult health status, height, wealth, and educational attainment, but only for women. They find no effect for men.

[4]Boklage (1990) finds that 73 percent of natural single conceptions have no real chance of surviving 6 weeks of gestation, with most wastage occurring before detection. Wilcox et al. (1988) find that 22 percent of all pregnancies fail to implant, and Wilcox et al. (1999) find that of those which implant, 25 percent fail to survive an additional 2 weeks. 50 to 70 percent never become an established pregnancy while over 75 percent of conceptions do not lead to birth (Wilcox et al. 1988).

[5]Liu et al. (2014) note that over half of all conceptions terminate before the mother knows she is pregnant.

in sub-Saharan Africa. We also test whether there is an effect on under-2 mortality. Our methodology relies on using region-month fixed effects to control for permanent geographic or seasonal characteristics which may affect these outcomes directly, allowing us to identify the effects using only the random variation in temperature. To do so, we merge gridded monthly weather data from Willmott and Matsuura (2012) at the University of Delaware with the region, month, and year of birth of individuals in Census records from six sub-Saharan African nations for which month of birth was reported (Burkina Faso, Cameroon, Guinea, Malawi, Rwanda and Uganda) found at IPUMS-international (Integrated Public Use Microdata Series).

We find that higher temperatures around the time of conception and immediately after birth are positively associated with better human capital outcomes later in life and lower child mortality. For example, a one standard deviation increase in temperature nine months before birth increases years of schooling by 0.06 years, which corresponds to a 1.15 percent increase from the mean. Similarly, the probability of being literate increases by 0.97 percent, while the probability of reporting any disability falls by 4.6 percent. The effect of heat immediately after birth is similar to the magnitude and direction of the effect at conception for years of schooling, but is twice as large as the effect at conception for disability. We do not detect any effect of temperature after birth for literacy.

Contrary to the fetal origins hypothesis, we do not find an effect of temperature in utero on any long-run human capital outcome.[6] This may be a provocative finding given the large literature on the Barker effect.[7] However, given the reduced form nature of our results, several alternative explanations may explain away this non-result. For example, parents may be engaged in compensatory investments in the human capital of the affected cohorts, or temperature in utero may cause both scarring and culling of the fetus, leaving the overall effect of temperature ambiguous and perhaps undetectable. Either way, our paper provides additional evidence and raises important questions for the literature on the fetal origins hypothesis.

[6]Our analysis estimates the effect of temperature for each month before birth, allowing us to distinguish temperature around the time of conception independently from temperature in utero.

[7]See Almond and Currie (2011) and Currie and Vogl (2013) for a recent review of the literature on the fetal origins hypothesis

We then tease out the unique mix of biological, behavioral, and selection effects by testing a series of potential mechanisms which may be driving these correlations. These channels include differential coital frequency by socioeconomic status during temperature spikes, heat-induced parental selection into conception, and intensified in utero selection. Using birth record data from the Demographic and Health Surveys (DHS), the Malaria Indicator Surveys (MIS), and the AIDS Indicators Surveys (AIS) for 29 countries in sub-Saharan Africa, we show that mothers with more education are more likely to conceive during heat waves than less educated mothers. We also show that this selection may be driven by a reduction in the extensive margin of sexual activity, which falls more for women with no education. We augment these findings by also showing reductions in the number of searches for sexually-themed Google searches during heat waves. But in spite of finding evidence that parents who conceive children during heat waves have better characteristics than those who do not, we show that there are no differences between estimates of the effect of temperature at conception with or without controls for parental education, suggesting that differences in parental characteristics are not driving our results.

Selection on fetal quality in utero may also explain our findings, so we test this channel in three ways. First, we test whether *known* terminations at any point during the pregnancy are correlated with temperature at the time of conception, and find that, contrary to our expectations, temperature *reduces* the probability that a pregnancy ends in termination. However, our analysis suggests that this result is most likely driven by induced abortion rather than miscarriage, suggesting that children conceived during heat waves are, on average, more wanted than those who are not. This is consistent with the fact that planned pregnancies are probably not timed around the incidence of a heat wave, meaning the reduction in conceptions during periods of high heat likely reflects a fall in unwanted pregnancies. Second, we find that heat waves at the time of conception affect the gender ratio, indicative of increased fetal loss. Finally, we find that the effect of temperature at conception on human capital outcomes is heterogeneous by gender. This also supports the fetal loss channel, since then the mean of the health distribution of surviving fetuses must be higher for males than for females if males are selected out at a higher rate via fetal loss. Taken together, our paper suggests that fetal loss is the most likely driver of the correlation between heat waves at conception and human capital outcomes later in life.

Beyond our contributions to the literature on temperature and long-run outcomes, our new focus on temperature at the time of conception, and our results contrary to the fetal origins hypothesis, our work also contributes to the literature on temperature and fertility rates.[8] While this literature finds that birth rates fall nine months after a heat wave, they do not identify the mechanisms driving this reduction. We show the first evidence that sexual activity falls with temperature, and also that temperature at the time of conception drives fetal loss. We also are the first study which uses Google search data to establish a link between high temperatures and reduced demand for online sexual services, strengthening our finding that sexual activity falls during heat waves.[9]

The paper proceeds as follows. Section 2 outlines our empirical methodology, and Section 3 presents our data. Section 4 presents our analysis on the correlation between temperature at conception and outcomes. Section 5 tests potential mechanisms by which temperature may affect outcomes later in life. Section 6 concludes.

2 Methodology

Estimating the effect of temperature at conception, in utero, and in early childhood on outcomes is not trivial. There are many reasons why absolute temperature should be correlated with outcomes even if no causal effect exists. For example, temperature is clearly correlated with seasons. But month of birth has also consistently been shown to be an important predictor of a large range of later life educational, health, and labor market outcomes.[10] Geographic characteristics may also be correlated with both weather and outcomes. For example, regions along coasts tend to have milder climates than

[8] Barreca et al. (2014); Lam and Miron (1991a, 1991b, 1994, 1996); Lam, Miron, and Riley, (1994); and Seiver (1985, 1989)

[9] Markey and Markey (2013) find a correlation between searches and seasonality in the United States, but only suggest that temperature may be driving search behavior.

[10] See Buckles and Hungerman (2013) section III for a review of this literature.

landlocked regions, and coastal regions also have higher economic development due to lower transportation costs. In contrast, locations at higher elevations are colder and have lower levels of economic development. The presence of these confounding factors in the permanent component of temperature imply that a naive regression of outcomes on temperature will yield incorrect estimates.

In this paper, we remove the permanent component of temperature by including region-month fixed effects in our regressions, leaving only the random component of temperature to identify the temperature effect. This is more demanding of the data than simply using a measure of demeaned temperature, since the fixed effect will also control for everything else specific to that region-month besides temperature. Formally, we estimate the following regression equation:

$$Y_{i,r,m,t} = \alpha_t + \theta_{r,m} + \sum_{j=t-15}^{t+3} \beta_j T_{j,i} + \psi X_{i,r,m,t} + \epsilon_{i,r,m,t}, \quad (1)$$

where Y_i is the outcome of interest for individual i at the time of the survey, α_t is a fixed effect for the year of birth, and $\theta_{r,m}$ is a fixed effect for the region-month of birth. In addition, there are up to 19 temperature variables $T_{j,i}$, corresponding to the average monthly temperature in the region of birth for each month from 15 months before the individual's birth to 3 months after birth. X_i is a vector of other explanatory variables.

The main coefficient of interest is β_{t-9}. If β_{t-9} is significantly different from zero, then heat waves at conception are partially correlated with outcomes. However, we may be interested in the coefficients on other βs as well. First, since not all conceptions occur precisely nine months before birth, we may expect that the coefficients on β_{t-10} and β_{t-8} will also pick up some of the effect of temperature at conception. Second, this specification not only allows us to look at the effect of temperature at the time of conception on outcomes, but also the effect of temperature before birth, in utero, and after birth. Finally, the coefficients on temperature before conception (β_{t-15} to β_{t-11}) provide a nice placebo test of our results, since there are few, if any, theoretical reasons why heat before conception should affect later life outcomes.

One potential source of bias in our estimates is migration after conception but before birth. Since we only observe the location of birth, and not the location of conception, we cannot be exactly sure that the individuals in our sample were exposed to heat deviations in their region of birth. This measurement error would bias our results towards zero. However, given the rates of migration observed in the Census data, we believe that the fraction of children who were conceived in a location different from their birth is small. In addition, since we find significant results on the effects of temperature at conception on outcomes, this possible attenuation bias strengthens our qualitative finding that temperature matters.

3 Data

We use two general types of data in this paper: data on temperature, and data on outcomes. Our outcomes data come from two different sources: African Census data from IPUMS International, and data from the MEASURE Demographic and Health Surveys (DHS) program. In addition, the analysis of one of our mechanisms uses an additional data set on Google search frequency in sub-Saharan Africa. We introduce each of these data sets in this section.

3.1 Temperature Data

In this paper, we use the gridded temperature dataset from Willmott and Matsuura (2012), housed at the University of Delaware, hereafter referred to as UDEL. These data are created by projecting temperature data from a large number of weather stations reported in the Global Historical Climate Network (GHCN) onto a 0.5×0.5 degree global grid. Table 1 contains some descriptive statistics for our sample. Panel A indicates that the average temperature at conception in our sample is 22.9°C. The standard deviation of temperature is small at only 0.759°C.[11] In addition, the average amount of precipitation is 102.1mm, with a standard deviation of precipitation shocks of 42.3mm.

[11] This standard deviation is for the temperature "shock" – the demeaned (by region-month) average temperature. This gives us a better sense of the size of the random temperature shocks than the unconditional standard deviation of temperature, which is necessarily higher due to differences in climate across space and seasons. The unconditional standard deviation is 3.01°C.

3.2 Census Data

Our Census data for sub-Saharan African countries are from Integrated Public Use Micro-data Series (IPUMS) International. By necessity we restrict our analysis to the countries which have data on region of birth, year of birth, month of birth, and at least one outcome of interest. In general, the constraining variable is the month of birth, which is missing for the majority of countries. We are left with nine Censuses in six countries for our analysis – Burkina Faso (1996 and 2006), Cameroon (1976 and 2005), Guinea (1996), Malawi (2008), Rwanda (1991, 2002), and Uganda (2002).

Using ArcGIS and sub-national shape files from IPUMS, we overlay the UDEL 0.5×0.5 degree global grid onto the sub-national regions in the Census to generate a monthly panel of temperature corresponding to our Census regions. Then using the region, month and year of birth given in the Census, and assuming that people are conceived nine months earlier in the same region they are born in, we can find the temperature at conception for each individual in our Census sample.

Table I, Panel B lists the four main outcomes we use from the Census data. For education, we have two measures of years of schooling. The first is a measure which we impute from educational attainment, while the second measures a self report of the number of years attended, independent of attainment.[12] The average individual in our sample has attained the equivalent of 5.23 years of schooling, while the attending on average 5.14. Literacy and No Disability are indicator variables which take a value of 1 if the individual is literate or not disabled.[13] 72.3 percent of individuals in our sample are literate whereas 97.2 percent are not disabled.

Since young children will have no variation in the number of years of schooling attained (since they are too young to attend school), we only keep individuals which who are old enough to show some heterogeneity in school attendance. Since a large fraction of children drop out after receiving only a few years of education, we observe a significant amount

[12]The Census data give very detailed educational attainment data which allows us to estimate the number of years of education attained with a high level of certainty. For example, rather than only reporting broad categories (such as primary, some primary, etc.), they report the actual number of years of primary, secondary, university, or trade school education.

[13]We invert the indicator for disability to be a 1 if the individual is not disabled so that a positive coefficient means a better outcome, consistent with the rest of our outcomes.

of heterogeneity in years of schooling by age 10, and drop individuals younger than this age.[14]

3.3 DHS / MIS / AIS Data

Since the number of variables in the Census is very limited, we augment our outcomes data using the Demographic and Health Surveys (DHS), Malaria Indicator Surveys (MIS), and AIDS Indicator Surveys (AIS) for a set of countries in sub-Saharan Africa between 1998 and 2012. They contain detailed information on the health of children and women as well as household characteristics. Using these data, we investigate the role of temperature at conception on mortality, as well as explore specific channels which may be driving the correlation between temperature and outcomes. A detailed list of the DHS data sets used in this analysis is provided in Table A.1 in the online appendix. The DHS/MIS/AIS data contains the region of residence of each individual, enabling us to merge the DHS data with the temperature data as we did with the Census data.

Using the DHS/MIS/AIS, we first investigate the relationship between temperature at conception and mortality in childhood using information on women's birth history. Our variable of interest is an indicator variable for whether a child is deceased at the time of the interview. We restrict our sample to children born in the 24 months preceding the interview. Table I, Panel C, shows that 5.3 percent of these children born to women in our sample have died by the time of the survey.

When we explore the channels relating temperature and outcomes, we pay particular attention to the mother's education and to household wealth. The mother's education variables are dummies indicating whether the mother completed at least primary education and whether she completed at least secondary education. For household wealth, we primarily employ a variable that gives the wealth quintile of the household. In some instances, we complement this indicator with dummies for whether the household has access to an improved source of drinking water or improved sanitation facilities.[15]

[14]Since we have year of birth fixed effects, the fact that these individuals may not have completed schooling is inconsequential: we are essentially testing for heterogeneity in schooling within each age cohort.

[15]Following the World Bank, we define an improved water source as any of the following sources: piped

We also check the role of terminated pregnancies and sexual activity in the relationship between temperature at conception and outcomes. Information on terminations come from calendar variables indicating whether a woman was pregnant, gave birth, or was using birth control for each month for 60 months before the interview. We restrict our sample to pregnancies with conception between the 31st and the 9th month before the interview (i.e. children who were born during the two years preceding the interview, and pregnancies which would have resulted in a live birth during the two years preceding the interview had the child remained alive).[16] The termination variable is a dummy that indicates whether that pregnancy ended in a termination. Terminations include both spontaneous and induced abortions – the data do not distinguish between these two types of termination. Table I, Panel C, indicates that 8.3 percent of pregnancies ended in termination.

When studying sexual activity, we drop women who never had intercourse or who were postpartum. The sexual activity variable is a dummy for whether the woman was sexually active during the four weeks preceding the interview. According to Table I, 68.0 percent of women were sexually active.

3.4 Google Data

To test the effect of temperature on sexual activity, we supplement our analysis with data on Google searches of sexually-themed words. Markey and Markey (2013) analyze Google searches for 25 sexually- or romantically-themed keywords from 2006 to 2011, and compare them with 21 control keywords. They find that searches for sexually-themed keywords exhibited seasonal variation in the United States. We employ a similar methodology.

Google Trends (http://www.google.com/trends/) enables users to download weekly data on the frequency of keyword searches by geographic area. In the United States, the

water into dwelling, piped water to yard/plot, public tap or standpipe, tubewell or borehole, protected dug well, protected spring, and bottled water. Improved sanitation facilities are defined as a flush toilet, a piped sewer system, septic tank, a flush/pour flush pit latrine, a ventilated improved pit latrine (VIP), a pit latrine with slab, or a composting toilet.

[16]Note that the calendar data is missing in a number of countries, so the sample we use to study terminations is smaller than the sample to study mortality.

geographic units can be as fine as an MSA, but in Africa internet connections are more rare. As a result, the finest geographic region is generally the entire country. Since the DHS and Census regions are subnational, we recalculated the UDEL temperature data at the national level using ArcGIS, then merged them with the Google search data. This resulted in a country-level panel dataset on monthly Google searches for each of the 46 keywords in Markey and Markey (2013).

We restrict our analysis to only five of the 46 keywords in Markey and Markey (2013) – sex, porn, Hotmail, Google, and Yahoo – since these are the only keywords for which there are five years or more of data. Rather than reporting an absolute measure of the number of searches for keywords, Google reports an index. We normalize each keyword's index to equal 100 at the mean frequency of searches over the five-year sample, allowing us to interpret the coefficients as the percentage change in searches from the mean.

4 Results

To explore the correlation between temperature at conception and outcomes later in life, we begin by estimating equation (1) using a number of educational and health outcomes. We use three different measures of educational attainment as our dependent variables: imputed of years of schooling based on educational attainment, the actual number of years of schooling, and a dummy for whether the individual is literate. To measure health outcomes, we have two main metrics. The first measures health status directly by using an indicator variable which takes the value of one if an individual reports having no disability in the Census data, while the second uses under-2 mortality in the DHS/MIS/AIS data.

4.1 Educational Outcomes

We find that temperature at the time of conception is positively correlated with our first measure of educational outcomes – the imputed years of schooling based on educational attainment. We report our results in Table II. Using our preferred specification with region-month fixed effects in Column (4), we find that an increase in the average monthly temperature of one Celsius degree is associated with an increase of approximately 0.0793 years of schooling. Since the standard deviation of temperature in an average region-month in our sample is 0.759 degrees, and the average level of schooling is 5.23 years, this implies that a one standard deviation increase in temperature increases years of schooling by 1.15 percent at the mean. While temperature is by no means the main driver of educational attainment, this result suggests that heat waves do have an economically significant impact.

Columns (5) and (6) show robustness of our main result in column (4). Given the large literature on the effects of precipitation in Africa, one may be concerned that our results are driven by changes in temperature when it rains.[17] Controlling for precipitation in column (5) does not change our results noticeably – the coefficient is 0.076 and still highly significant. Moreover, we find a negative correlation between precipitation at the time of conception and education later in life. Since our precipitation measure is in millimeters, and the standard deviation of precipitation in our sample is about 42.3, a coefficient of -0.0004 implies that a one standard deviation increase in rainfall reduces education by about 0.32 percent at the mean, about one-fourth the size the temperature effect.

In Column (6) we show that our results at the time of conception are robust to the inclusion of additional temperature variables for all months from 15 months before birth to three months after. Beyond robustness, including these other temperature variables are useful for four reasons. First, since gestation lengths are highly variable, and many births occur eight or ten months after conception, one may be concerned that by only including temperature at nine months before birth does not measure temperature at conception precisely. The fact that we find an effect of temperature on outcomes *only* for the three months mostly likely to be associated with conception (10, 9 and 8 months before birth) strengthens our assertion that this is actually a conception effect. Second, if temperature shocks are highly persistent month to month, a shock at the time of conception could be

[17] The correlation between rainfall and temperature in our data set is -0.034, implying that it becomes slightly cooler when it rains. Although this correlation is somewhat small, it is still highly statistically significant.

correlated with a temperature shock earlier or later in the pregnancy. In this case, we could be picking up the effect of early in utero exposure to temperature on the coefficient for temperature at the time of conception.[18] Third, it enables us to conduct a placebo test to see if we find an effect of temperature before conception, which we do not. Finally, it allows us to explore the effect of temperature in utero and in early life.

In Table II we find no effect of temperature in utero on educational attainment. The lack of results for temperature in utero provides evidence against a Barker effect. This is quite notable given the large literature in economics and other fields devoted to testing Barker's fetal origins hypothesis.[19] However, like most of the literature on this topic, we cannot conclusively disprove the Barker hypothesis with our results for two main reasons. First, temperature may not be an appropriate in utero shock since Barker's hypothesis was mainly in the context of the intrauterine nutritional environment, not maternal stress in general. Second, we cannot control for differential investment in less healthy children after birth, which could possibly mask a Barker effect given our reduced form methodology. Nevertheless, the results of this paper do constitute an important piece of evidence that in utero temperature shocks are not associated with worse health outcomes as adults.

We also find an effect of temperature after birth on educational attainment. This is consistent with the findings of Kudamatsu et al. (2012) who find that temperature shocks immediately after birth in malarious and drought-prone regions of Africa lead to higher infant mortality. Since weaker children (or children from low-income parents) may be disproportionately affected by a poor mortality environment, those who survive may have better characteristics on average.

In Tables A.2 in the Online Appendix and Table III we report our results for the direct years of schooling measure and literacy. The direct years of schooling results almost exactly match those for imputed years of schooling. The effect of temperature

[18] We also estimate an AR model on monthly temperature deviations and find that the first order AR coefficient is 0.2, and all subsequent coefficients are zero, implying that temperature deviations do not persist much month to month. We also estimate a model with leads instead of lags and find similar results.

[19] See Almond and Currie (2011) and Currie and Vogl (2013) for recent summaries of the literature.

at the time of conception is still positive and significant, while temperature is also only significant around the time of conception and after birth, but not in utero. The only noticeable difference is that the coefficients are slightly larger than before, which could be explained by the measurement error introduced previously when imputing years of schooling from attainment.

Our results on literacy also match the years of schooling results. Using the coefficients in our preferred specification in Column (4) of Table III, we find that a one standard deviation increase in temperature at the time of conception leads to a 0.66 percentage point increase in the probability of being literate as an adult, or an increase in literacy of 0.97 percent from the mean. This is very similar to our estimated increase in years of schooling of 1.15 percent from Table II. The only notable difference from our results for years of schooling is that the effect of temperature after birth is no longer statistically significant for literacy.

4.2 Health Outcomes

Table IV presents our results on disability. Our preferred specification in column (4) shows that a one degree increase in the average monthly temperature at the time of conception decreases the probability of being disabled by 0.17 percentage points. Since only 2.8 percent of individuals in our sample report being disabled, this implies that a one standard deviation increase in temperature decreases disability by 4.61 percent – an effect which is 3 to 4 times larger than our results on years of schooling. We also find a large effect for temperature immediately after birth, just like we did for education. However, unlike our results on education, we find an effect of temperature in utero. The coefficient values for all months in utero are just as large as the effect at conception.

We also find that temperature at the time of conception reduces under-2 mortality. Using the birth history of women from the DHS/MIS/AIS data, we regress a dummy for whether the child is dead at the time of the interview on temperature at conception. We restrict our sample to children born within the two years preceding the interview. The results are reported in Table V. We find that children who are conceived during a heat wave are less likely to die in early childhood. For example, we find that a one standard deviation increase in temperature at conception decreases the probability of death by 0.37 percentage points in our preferred specification in column (4). Since 5.3 percent of children under two are dead by the time of the survey in our sample, this corresponds to a 7.0 percent reduction in child mortality.

5 Channels

In the previous section, we established that heat waves at the time of conception are associated with better educational attainment, literacy, and lower rates of disability as adults. We also showed a reduction in under-2 mortality. In this section, we seek to answer why these correlations exist. We focus on two possible explanations: selection of parents with different human capital and wealth characteristics into conception based on ambient temperature, and heat-dependent selection on the health of the fetuses themselves. For each channel, we begin by explaining the theoretical reasons for the mechanism, and then provide evidence for or against it. We conclude this section by discussing other possible explanations we were unable to test with our data.

5.1 Selection on Parental Characteristics

Temperature may induce different groups of women to become pregnant at different times, either intentionally or unintentionally. For example, Buckles and Hungerman (2013) show that there is a significant amount of seasonality in educational attainment and marital status of childbearing women. Children born in winter are more likely to have a mother who is a teenager, has low education, or is a single. One possible explanation for their finding is temperature. Hot temperatures may reduce sexual activity (Barreca et al. 2014, Lam and Miron 1996). These reductions may be disproportionately large for those unable to invest in technologies to shield themselves from the heat (e.g. air conditioning, etc.). As a result, fertility may fall faster nine months after a heat wave among women with lower education and socioeconomic status. This would change the mix of women conceiving children during heat waves, inducing a correlation between maternal characteristics and temperature at conception. Similarly, since women are unlikely to plan their pregnancies around something so trivial as a heat wave, the majority of the reduction in conceptions may be among unwanted pregnancies. If parents invest less resources in unwanted children, this may result in lower human capital later in life.

Temperature may also affect fecundity heterogeneously for women of different socioeconomic groups. For example, increased body temperature may negatively impact ovulation and lead to irregular menstruation or failed implantation. Temperature also affects male fecundity through lower semen quality and testosterone levels.[20] If the fecundity of lower socioeconomic status women is disproportionately affected by temperature spikes (either directly or through their partners), this could lead to a lower number of births by less educated and poorer women. Both of these channels may affect the mix of women who conceive during heat waves, causing the average child conceived during a heat wave to have a mother with better characteristics, and thereby better outcomes later in life.

5.1.1 Sexual Activity

We begin our analysis by testing whether sexual activity during heat waves depends on socioeconomic status. Using the DHS/MIS/AIS data, we regress a dummy for whether a woman was sexually active in the four weeks preceding the interview on temperature during and up to two months before the interview. The results are given in Table VI. We find that sexual activity decreases with temperature during the month of the interview, consistent with the fall in fertility found in Barreca et al. (2014) and Lam and Miron (1996). In addition, in column (4) we find a positive coefficient on the interaction between temperature and having at least a primary eduction, implying that the decrease in sexual activity is smaller for educated women. Our results imply that a one standard deviation increase in temperature reduces the extensive margin of sexual activity by 1.74 percentage points for women without a primary education, compared with a 1.08 percentage point

[20]See Barreca et al. (2014) for an extensive review of the literature on temperature and fecundity.

decrease for women with at least a primary education. Since 68.0 percent of women in our sample are sexually active, this implies a 2.56 and 1.58 percent reduction in sexual activity respectively. We do not find differential effect of temperature on sexual activity across women of different wealth quintiles.

We augment our analysis of the extensive margin of sexual activity with data on the frequency of internet searches for a series of sexually-themed words in sub-Saharan Africa. If reductions in sexual activity occur due lower libido during heat waves, we should find that demand for other sexual activities (such as looking at pornography online) falls during heat waves as well. To measure Google searches, we use data from Google Trends for the two sexually-themed keywords ("sex" and "porn") and the three control keywords ("Hotmail", "Google", and "Yahoo") used in Markey and Markey (2013) which have at least five years of data.

In Table VII, we find that temperature spikes reduce the frequency of searches for sexually-themed words. Columns (1) and (2) show that a one standard deviation increase in temperature reduce searches for "sex" by 1.56 percent and "porn" by 2.29 percent. Each regression includes region-month fixed effects, as well as controls for the three control words measuring general internet usage. Since we normalize the searches to be 100 at the mean level of searches, the coefficients in Table VII can be interpreted as percentage changes from the mean. Column (3) aggregates searches for the two sexually-themed words together, and the three control words together, and regresses the aggregated sexual words index on temperature and the aggregate internet use index. We find a similar decrease in the search frequency of sexually themed words by 1.80 percent. Finally, in column (4) we take the ratio of the sexual searches index and the control index to create an index of sexual searches normalized by the control searches, since temperature may also affect the amount of internet use. We find that a one standard deviation increase in temperature decreases aggregate searches for "porn" and "sex" by 4.15 percent.

5.1.2 Parental Characteristics

Next we test directly whether mothers who conceive during heat waves have better human capital and wealth outcomes. To test this channel, we regress a series of maternal outcomes from the DHS/MIS/AIS data set on the temperature when women conceived their children. The results are reported in Table VIII. In column (1), we find that women who conceive during heat waves are more likely to have primary eduction, consistent with our findings in Table VI which show that women with at least a primary education are more likely to be sexually active during high temperatures. But we do not find that they are more likely to have completed secondary education. In addition, we find no difference in wealth, and mixed results on the likelihood of having improved sanitation or water for women who conceive during heat waves, which is also consisted with Table VI. Our findings here suggest only limited support that differences in parental socioeconomic and educational status drive the correlation between temperature at conception and later life outcomes.

We then analyze whether the effect of temperature on education and health outcomes remains significant after controlling for parental characteristics. Unfortunately, there is no information in the Census data on parental characteristics, except for adults who live in the same household as their parents. Approximately 1/4th of the sample falls into this category. Although this subset is likely unrepresentative of the population as a whole, we re-run our original analysis from Tables II through IV with this smaller sub-sample while controlling for both mother's and father's education. We also re-estimate our results on under-2 mortality in the DHS/MIS/AIS data from Table V controlling for parents' education.

We report our results in Table IX. We find that controlling for parental characteristics has no effect on the magnitude or significance of the coefficient for temperature at the time of conception. In fact, the estimated coefficients go up slightly in all cases except for under-2 mortality. We conclude that differences in parental characteristics do not explain why heat waves at conception are correlated with outcomes later in life.

5.2 Selection on Fetal Strength

The positive correlation between temperature at conception and later life outcomes may be due to selection in utero. If weaker fetuses are more likely to die in utero due to a temperature shock, then the stronger, healthier fetuses are more likely to survive, potentially leading to a more educated and healthier population in adulthood. However, spontaneous abortions are difficult to measure, since over 50 percent of spontaneous abortions occur before the mother knows she is pregnant (Liu et al. 2014).

We test the fetal selection channel in three ways. First, using a pregnancy outcome questionnaire in the DHS/MIS/AIS, we regress an indicator which takes a value of one if a pregnancy is terminated before birth for any reason on temperature three months before the month the woman first reports being pregnant (MRP) to one month after. The results are reported in Table X. The estimates provide clear evidence that temperature around the probable time of conception (one month before she first reports being pregnant) is negatively associated with termination, and for no other time. For example, the coefficient in column (4) of Table X implies that a one standard deviation increase in temperature decreases the probability that a women experiences a known termination before birth by 0.49 percentage points. Since 8.3 percent of women in our sample experience a termination, this implies a 5.85 percent decrease in terminations from the mean.

There are two interesting observations about this finding. First, this reduction is quite large. In addition, finding a decrease in terminations seems to contradict our hypothesis that fetal loss should increase during heat waves. However, that would only be true if the termination variable correctly measured fetal loss. In columns (1) and (6), we show our termination variable is actually positively correlated with education and wealth. If the termination variable was driven by fetal loss, those coefficients should have been negative. But we do know that induced abortion is positively correlated with income and education in Africa (Rominski et al. 2014). Since the termination variable does not distinguish between spontaneous and induced abortion, we believe that the termination variable is more likely measuring induced abortions rather than fetal loss through spontaneous miscarriages.

Given that interpretation, our results in Table X suggest that induced abortions fall if a child is conceived during a heat wave. Sexual activity falls during heat waves, and since it is unlikely that people plan their children based on the ambient temperature, it makes sense that a higher fraction of intended children would be conceived during periods of high temperatures. Inasmuch as parents invest more in children who are more wanted, this could translate into better outcomes for these children later in life, not because of biological selection or parental quality, but rather from higher parental investments once the children are born.

Second, we test for fetal loss by investigating the effect of temperature on the sex ratio. Since males require more maternal resources to form and carry full term than females and tend to be more fragile in utero, during periods of fetal stress the gender ratio skews female (Catalano et al. 2005, Catalano et al. 2006, Catalano and Bruckner 2006, Liu et al. 2014, Hernàndez-Juliàn et al. 2014). Using our Census data, we regress an indicator variable for whether the respondent is female on the temperature at conception, restricting our sample to individuals less than the age of 2 to reduce the bias from selective mortality after birth. Our results are presented in Table XI. In our preferred specification in column (4), we find that a one standard deviation increase in temperature at conception increases the probability of a female birth by 0.17 percentage points. This provides support for our fetal loss hypothesis, and implies that weaker fetuses are being selected out during heat waves at the time of conception. The surviving stronger fetuses are then more likely to have better outcomes as adults.

Finally, we test for heterogeneous effects of temperature at conception on outcomes by gender. If heat waves select out a larger fraction of males than females, then the mean health of the remaining male fetuses should be better than for females since they were subject to stronger selective pressure. As a result, we would expect the effect of temperature at conception on outcomes to be stronger for males. In Table XII we find this exact result. We regress each of our four Census outcomes on temperature at the time of conception, a dummy for being a female, and the interaction of female and temperature. A negative coefficient on the interaction term suggests that the temperature effects are smaller for females – consistent with the theory that fetal loss is driving the outcomes results. For our education measures, the effect of a one Celsius degree increase in temperature at conception for males is more than double that for females (0.109 vs. 0.047 and 0.129 vs 0.0537 for our attainment based measure and years of schooling measure respectively). Similarly, the effect for males on literacy is double that for females (0.108 vs. 0.055), and the effect on disability is higher by a third (0.0019 vs 0.0014).

5.3 Other Mechanisms

A few additional theories of how temperature at conception may affect outcomes are worth mentioning. First, heat waves at conception may be correlated with income, especially in sub-Saharan Africa where a sizable fraction of the population is employed in subsistence farming.[21] This lower income at the time of conception may lead to poorer nutrition and maternal health, thereby affecting the probability of conception or implantation, as well as damaging the fetus.[22]

These income effects are not likely to drive our results for three reasons. First, while it is highly likely that the annual temperature deviations used to identify income in these studies affect output, the effect of shorter monthly temperature deviations used in our paper is less clear. Temperature should only matter during months pivotal for agricultural production, not year round.[23] Second, higher temperatures in one month resulting in a poor harvest would affect prices and incomes (and thereby nutrition) for months afterwards, not just during the month of the heat wave. Since we only find an effect for heat waves at the time of conception, we find this explanation less likely, although we cannot rule it out. Finally, even if our results were driven by poor nutrition

[21]While Dell, Jones, and Olken (2012) and Hsiang (2010) find that temperature in North American and the Caribbean is negatively associated with income, Barrios, Bertinelli, and Stobl (2010) do not find an effect in sub-Saharan Africa. Instead, they find that income is much more sensitive to rainfall, similar to the findings of Brückner and Ciccone (2011). Focusing just on agricultural output, Schlenker and Lobell (2010) do find a negative effect of temperature on crop yields in sub-Saharan Africa.

[22]Poor nutrition could also result from general equilibrium effects of temperature, such as increases in food prices.

[23]Our results are average treatment effects of temperature over all months in the year, not just these pivotal windows.

from lowered income, the fetal loss mechanism we identify as the most likely driver of our results would still be operative – poor nutrition at the time of conception would cause intensified fetal loss, increasing the average human capital of the surviving cohort.

Another potential mechanism runs through cohort size. Since heat waves reduce fertility, cohorts of children conceived during heat waves will be smaller. These smaller cohorts could have higher investment in human capital per capita after birth through public goods provision (smaller class sizes, less overcrowding of health clinics, etc.) or by moving parents along the quality/quantity frontier of child rearing. In addition, a smaller cohort may increase the returns to labor, thereby increasing wages of the affected cohorts which could lead to more human capital investments.

Cohort size effects are not likely to be the main driver of our results for three reasons. First, the heat waves in this study are monthly deviations, which are too short of a time frame to significantly alter the demographic structure of society. A small monthly cohort conceived during a heat wave would be put into the same school class as eleven other monthly cohorts, some of which would be born during normal temperatures and some during low temperatures. It is hard to believe that a one-month temperature spike would significantly alter the size of an annual school class. Second, the magnitudes of the fertility effect from Lam and Miron (1996) and Barreca et al. (2014) are much too small to significantly alter cohort size. For example, Barreca et al. (2014) find an additional 95 degree day (Fahrenheit) instead of a 65 degree day would reduce birthrates only by 0.7 percent. In our paper, this would translate into an increase in average monthly temperatures of 0.55 Celsius degrees, or a 0.72 standard deviation of temperature. As a result, a one standard deviation increase in temperature would reduce the size of the cohort by 0.97 percent. It is hard to believe that such a small decrease in cohort size could be responsible for the magnitude of the effects we find in this paper. Finally, labor is highly substitutable between cohorts, meaning we should not expect to find a significant difference in wages simply due to reduced labor supply in one monthly cohort.

6 Conclusion

Using Census data for six sub-Saharan African countries, a combined dataset of DHS/MIS/AIS surveys for 29 sub-Saharan countries, and weather data from the University of Delaware, this paper shows that temperature extremes at the time of conception are associated with better human capital outcomes later in life. Specifically, we find that educational attainment and literacy rise for individuals who were conceived during heat waves, whereas reported disability status and under-2 mortality decrease. We also show that temperature after birth plays an important role in explaining differential outcomes later in life, but find no role for temperature in utero.

To explain these findings, we explore a number of mechanisms that could underlie the relationship between temperature at conception and later life outcomes. We show that sexual activity falls during heat waves in the DHS/MIS/AIS data, as well as Google searches for sexually-themed words. Most importantly, we show that sexual activity falls less for women with at least primary education, implying that women with better characteristics may select into pregnancy based on heat waves. However, we can only show mixed evidence that these women are in fact more educated. We also find mixed evidence they have higher socioeconomic status as measured by wealth or living conditions. Finally, when we control explicitly for parental characteristics of individuals whose parents live in the same household, we find that differences in these characteristics do not drive our results.

We then focus on the role of in utero selection. We show that known terminations are lower when heat waves occur in the month before a woman first reports being pregnant. Given the positive correlation between these terminations and socioeconomic characteristics, we interpret this finding as showing that unintended conceptions fall during heat waves. We also find that the gender ratio of individuals born nine months after a heat wave skew more female, indicative of intensified fetal loss. Finally, the effect of temperature on outcomes is significantly larger for males, also consistent with a fetal loss story.

This work contributes to the literature in several important ways. First, this is the first paper to analyze the effect of temperature before and just after birth on long-run human capital outcomes. Second, this is the first paper to focus on the effect at conception and test the unique behavioral and biological channels through which the conception effect may operate. We also contribute to the literature on temperature and fertility by demonstrating that heat waves are accompanied with increased fetal loss and declines in sexual activity. Finally, our work speaks to the Barker hypothesis which states that shocks in utero may have long lasting effects. We find they do not. However, the reduced form nature of our analysis cannot rule out differential investments in human capital among affected cohorts after birth, which potentially could mask a Barker effect.

Our study also has implications for health, educational, and development policies in the developing world. Knowing that temperature at the time of conception leads to fetal loss may cause policy makers to place a higher importance on programs which aim to reduce the negative effects of heat, such as increased electrification and the proliferation of air conditioning. This would be especially important for women trying to conceive and women who have just given birth.

Some have interpreted our findings as evidence that global warming is good for economic growth, since we find that higher temperatures lead to lower fertility and higher human capital. However, we take the opposite view. These benefits come at a human cost of increased fetal loss. Miscarriage often comes with a high psychological and biological cost to parents, especially if these lost pregnancies were wanted. It also increases the probability that a couple will not be able to achieve their desired fertility. It is hard to imagine that such a tradeoff could be welfare maximizing. As a result, our study provides additional insight into the costs of global warming, which may raise the benefit of policies aimed at slowing climate change.

However, one must also be cautious when interpreting our results in relation to global warming. Since our identification comes from high-frequency deviations from temperature means, it is entirely possible that as global temperatures rise, people will adapt.[24] Our

[24]Dell et al. (2014) provides a detailed discussion of the pitfalls of interpreting panel estimates of temperature on outcomes in the face of adaptation.

paper unfortunately says nothing about this adaptation.[25] As a result, determining the extent to which human populations will adapt their behavior in the face of climate change, and how this adaptation may affect long-run outcomes, is a possibly fruitful area of future research.

In addition, our evidence against the Barker effect constitutes an important, if not provocative, contribution to the literature. But this result also needs more study. Establishing whether parents invest more in children with lower human capital is essential to understand whether the reduced form analyses such as those used in this paper can reasonably be used as evidence to reject the fetal origins hypothesis. The questions answered and raised by this paper inform key debates over the root causes of human capital formation – debates which are not only integral in determining correct policies aimed at reducing poverty in the developing world, but also strike at the very heart of the key questions asked by labor and development economists.

[25] Here we refer to behavioral adaptation, since biological or evolutionary adaptation to higher temperatures is unlikely to occur rapidly enough to mitigate the effect of rising temperatures over the next century.

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Tables

Table I: Summary Statistics

Variable	Mean	Standard Deviation
Panel A. Weather Data		
Temperature at Conception (°C)	22.9	0.759
Precipitation at Conception (mm)	102.1	42.3
Panel B. Census Data		
Years of Schooling – Imputed from Attainment	5.23	4.27
Years of Schooling	5.14	4.04
Literacy	0.723	0.448
No Disability	0.972	0.165
Mother's Years of Schooling	3.36	4.11
Father's Years of Schooling	5.16	4.70
Female	0.507	0.500
Panel C. DHS / AIS / MIS Data		
Death (Child Mortality)	0.053	0.224
Sexual Activity	0.680	0.467
Terminated Pregnancy	0.083	0.276
Mother's Primary Education +	0.616	0.486
Mother's Secondary Education +	0.237	0.425
Wealth Index	3.13	1.44
Improved Sanitation	0.267	0.442
Improved Water	0.593	0.491

Table II: Temperature and Years of Schooling Based on Local Educational Attainment in the Census

	(1) Years of Schooling (Attainment)	(2) Years of Schooling (Attainment)	(3) Years of Schooling (Attainment)	(4) Years of Schooling (Attainment)	(5) Years of Schooling (Attainment)	(6) Years of Schooling (Attainment)
Temperature at Birth - 15						0.0167
						(0.0126)
Temperature at Birth - 14						0.0149
						(0.0137)
Temperature at Birth - 13						-0.00933
						(0.0126)
Temperature at Birth - 12						0.00288
						(0.0124)
Temperature at Birth - 11						0.0129
						(0.0133)
Temperature at Birth - 10						0.0225*
						(0.0130)
Temperature at Birth - 9	0.0932***	0.0743***	0.0652***	0.0793***	0.0760***	0.0314**
	(0.0008)	(0.0066)	(0.0062)	(0.0140)	(0.0140)	(0.0135)
Temperature at Birth - 8						0.0261**
						(0.0126)
Temperature at Birth - 7						0.0139
						(0.0132)
Temperature at Birth - 6						0.0155
						(0.0128)
Temperature at Birth - 5						-0.0082
						(0.0134)
Temperature at Birth - 4						-0.0036
						(0.0110)
Temperature at Birth - 3						0.0016
						(0.0145)
Temperature at Birth - 2						0.0147
						(0.0128)
Temperature at Birth - 1						-0.0028
						(0.0144)
Temperature at Birth						0.0084
						(0.0148)
Temperature at Birth + 1						0.0280**
						(0.0134)
Temperature at Birth + 2						0.0289**
						(0.0147)
Temperature at Birth + 3						0.0379***
						(0.0120)
Precipitation at Birth - 9					-0.0004***	
					(0.0001)	
Region FE		Yes	Yes			
Year FE		Yes	Yes	Yes	Yes	Yes
Month FE			Yes			
Region-Month FE				Yes	Yes	Yes
Observations	3,640,483	3,640,483	3,640,483	3,640,483	3,640,483	3,640,483
R-squared	0.004	0.222	0.223	0.224	0.225	0.225

Notes: The dependent variable is the number of years of schooling, imputed from a measure of educational attainment found in the Census data. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. "Precipitation at Birth - 9" refers to the precipitation level nine months before birth measured in millimeters. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table III: Temperature and Literacy in the Census

	(1) Literate	(2) Literate	(3) Literate	(4) Literate	(5) Literate	(6) Literate
Temperature at Birth - 15						0.0018*
						(0.0011)
Temperature at Birth - 14						0.0013
						(0.0013)
Temperature at Birth - 13						-0.0009
						(0.0012)
Temperature at Birth - 12						0.0006
						(0.0013)
Temperature at Birth - 11						0.0015
						(0.0012)
Temperature at Birth - 10						0.0027**
						(0.0013)
Temperature at Birth - 9	-0.0070***	0.0063***	0.0058***	0.0083***	0.0083***	0.0032**
	(9.04e-05)	(0.0005)	(0.0005)	(0.0012)	(0.0012)	(0.0012)
Temperature at Birth - 8						0.0036***
						(0.0011)
Temperature at Birth - 7						0.0021
						(0.0013)
Temperature at Birth - 6						0.0028**
						(0.0013)
Temperature at Birth - 5						0.0005
						(0.0013)
Temperature at Birth - 4						0.0013
						(0.0012)
Temperature at Birth - 3						0.0013
						(0.0013)
Temperature at Birth - 2						0.0008
						(0.0011)
Temperature at Birth - 1						-0.0005
						(0.0012)
Temperature at Birth						0.0004
						(0.0014)
Temperature at Birth + 1						0.0012
						(0.0014)
Temperature at Birth + 2						0.0007
						(0.0016)
Temperature at Birth + 3						0.0002
						(0.0013)
Precipitation at Birth - 9					-3.48e-07	
					(1.32e-05)	
Region FE		Yes	Yes			
Year FE		Yes	Yes	Yes	Yes	Yes
Month FE			Yes			
Region-Month FE				Yes	Yes	Yes
Observations	3,600,947	3,600,947	3,600,947	3,600,947	3,600,947	3,600,947
R-squared	0.002	0.150	0.151	0.152	0.152	0.152

Notes: The dependent variable is an indicator variable which takes a value of one if the individual reports being literate in the Census. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. "Precipitation at Birth - 9" refers to the precipitation level nine months before birth measured in millimeters. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table IV: Temperature and Reported No Disability in the Census

	(1) No Disability	(2) No Disability	(3) No Disability	(4) No Disability	(5) No Disability	(6) No Disability
Temperature at Birth - 15						0.0005***
						(0.0001)
Temperature at Birth - 14						0.0005***
						(0.0001)
Temperature at Birth - 13						0.0006***
						(0.0001)
Temperature at Birth - 12						0.0003*
						(0.0002)
Temperature at Birth - 11						0.0001
						(0.0002)
Temperature at Birth - 10						0.0001
						(0.0001)
Temperature at Birth - 9	0.0021***	0.0001**	0.0003***	0.0017***	0.0017***	0.0004**
	(2.99e-05)	(6.78e-05)	(7.68e-05)	(0.0001)	(0.0001)	(0.0001)
Temperature at Birth - 8						0.0004**
						(0.0001)
Temperature at Birth - 7						0.0003**
						(0.0001)
Temperature at Birth - 6						0.0005***
						(0.0001)
Temperature at Birth - 5						0.0003*
						(0.0001)
Temperature at Birth - 4						0.0005***
						(0.0001)
Temperature at Birth - 3						0.0003*
						(0.0001)
Temperature at Birth - 2						0.0003**
						(0.0001)
Temperature at Birth - 1						0.0005***
						(0.0002)
Temperature at Birth						0.0008***
						(0.0002)
Temperature at Birth + 1						0.0003*
						(0.0001)
Temperature at Birth + 2						0.0007***
						(0.0001)
Temperature at Birth + 3						0.0005***
						(0.0001)
Precipitation at Birth - 9					5.50e-06**	
					(2.64e-06)	
Region FE		Yes	Yes			
Year FE		Yes	Yes	Yes	Yes	Yes
Month FE			Yes			
Region-Month FE				Yes	Yes	Yes
Observations	3,620,457	3,620,457	3,620,457	3,620,457	3,620,457	3,620,457
R-squared	0.001	0.012	0.012	0.012	0.012	0.013

Notes: The dependent variable is an indicator variable which takes a value of one if the individual reports having no disability in the Census. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. "Precipitation at Birth - 9" refers to the precipitation level nine months before birth measured in millimeters. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table V: Temperature and Under-2 Mortality in the DHS / MIS / AIS

	(1) Death	(2) Death	(3) Death	(4) Death	(5) Death
Temperature at birth - 15					-0.0000
					(0.0016)
Temperature at birth - 14					0.0012
					(0.0017)
Temperature at birth - 13					0.0021
					(0.0017)
Temperature at birth - 12					0.0029*
					(0.0017)
Temperature at birth - 11					0.0002
					(0.0018)
Temperature at birth - 10					-0.0020
					(0.0017)
Temperature at birth - 9	0.0001	-0.0003	-0.0008**	-0.0049***	-0.0036**
	(0.0002)	(0.0003)	(0.0004)	(0.0014)	(0.0016)
Temperature at birth - 8					-0.0009
					(0.0017)
Temperature at birth - 7					-0.0047***
					(0.0017)
Temperature at birth - 6					0.0015
					(0.0017)
Temperature at birth - 5					-0.0012
					(0.0018)
Temperature at birth - 4					0.0004
					(0.0017)
Temperature at birth - 3					0.0004
					(0.0017)
Temperature at birth - 2					-0.0024
					(0.0017)
Temperature at birth -1					0.0021
					(0.0018)
Temperature at birth					-0.0005
					(0.0016)
Region FE		Yes			
Year of birth FE		Yes	Yes	Yes	Yes
Month of birth FE					
Region-Month of birth FE				Yes	Yes
Observations	101,480	101,480	101,480	101,480	101,480
R-squared	0.0000	0.0075	0.0077	0.0428	0.0430

Notes: The dependent variable is an indicator variable which takes a value of one if the child is dead at the time of the interview. The sample is restricted to children who are (or would have been) less than two years old at the time of the interview. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VI: Temperature and Sexual Activity in the DHS / MIS / AIS

	(1) Sexually Active	(2) Sexually Active	(3) Sexually Active	(4) Sexually Active
Demeaned Temperature at Interview		-0.0172***	-0.0165***	-0.0229***
		(0.0040)	(0.0041)	(0.0074)
Demeaned Temperature at Interview - 1			-0.0050	-0.0044
			(0.0039)	(0.0036)
Demeaned Temperature at Interview - 2			0.0052	0.0059
			(0.0038)	(0.0036)
Primary Edu +	-0.0479***			-0.0468***
	(0.0040)			(0.0040)
Wealth Index	-0.0092***			-0.0092***
	(0.0014)			(0.0014)
Primary Edu +*Temperature				0.0087**
				(0.0041)
Wealth*Temperature				0.0019
				(0.0015)
Year of Birth FE	Yes	Yes	Yes	Yes
Age of Mother FE	Yes	Yes	Yes	Yes
Observations	356,908	356,908	356,908	356,908
R-squared	0.0253	0.0221	0.0222	0.0259

Notes: The dependent variable is an indicator variable which takes the value of one if the respondent was sexually active in the four weeks preceding the interview. Demeaned Temperature at Interview - X refers to the demeaned temperature in Celsius degrees prevailing in the respondent's region X months before the interview. The "Temperature" variable in the interaction terms is the detrended temperature at the time of interview. The wealth index is measured in quintiles, where 1 means you belong to the poorest 20 percent of respondents, while a 5 means you are in the richest 20 percent of respondents. All regressions include fixed effects for year and age of the mother, and are clustered at the region-month level. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VII: Temperature and Google Searches in Africa

	(1) Searches: "Sex"	(2) Searches: "Porn"	(3) Sexual Searches Index	(4) Normalized Index
Temperature	-2.0525**	-3.0186*	-2.3724**	-5.4691***
	(1.0539)	(1.6869)	(1.1255)	(1.5345)
Internet Use			-0.2755***	
			(0.0822)	
"Yahoo"	-0.1071**	-0.0184		
	(0.0489)	(0.0640)		
"Google"	0.0060	-0.1165		
	(0.0457)	(0.0779)		
"Hotmail"	-0.1136***	-0.0704		
	(0.0283)	(0.0451)		
Year of Birth FE	Yes	Yes	Yes	Yes
Region-Month of Birth FE	Yes	Yes	Yes	Yes
Observations	996	788	785	785
R-squared	0.4368	0.6329	0.5934	0.5802

Notes: The dependent variables are indexes of search frequency normalized to the mean level of searches during the sample period (2004-2010). The "Sexual Searches Index" is a composite index of searches of "sex" and "porn", while the "Normalized Index" is the sexual searches index divided by "Internet Use", a composite index of searches for the three control words "Yahoo", "Google", and "Hotmail". All regressions include year and region-month fixed effects. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table VIII: Temperature and Parents' Characteristics in the DHS / MIS / AIS

	(1) Mother's Primary Edu +	(2) Mother's Secondary Edu +	(3) Wealth Index	(4) Improved Sanitation	(5) Improved Water
Temperature at Birth - 9	0.0051**	-0.0036	-0.0066	0.0070*	0.0002
	(0.0025)	(0.0028)	(0.0103)	(0.0039)	(0.0038)
Year of Birth FE	Yes	Yes	Yes	Yes	Yes
Region-Month of Birth FE	Yes	Yes	Yes	Yes	Yes
Observations	86,915	86,915	90,130	88,516	88,263
R-squared	0.4298	0.2602	0.2745	0.2687	0.1936

Notes. The sample contains mothers who gave birth in the two years preceding the interview. "Mother's Primary +" indicates that the mother's level of education is at least primary. "Mother's Secondary +" indicates that the mother's level of education is at least secondary. "Wealth Index" measures the wealth quintile of the individual. Standard errors, clustered at the region-month of birth level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table IX: Temperature and Outcomes Controlling for Parents' Characteristics in the Census and in the DHS / MIS / AIS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Census								
	Years of Schooling (Attainment)	Years of Schooling (Attainment)	Years of Schooling (Direct)	Years of Schooling (Direct)	Literate	Literate	No Disability	No Disability
Temperature at Birth - 9	0.0228*	0.0262**	0.0418***	0.0439***	0.0115***	0.0118***	6.13e-05	6.22e-05
	(0.0122)	(0.0120)	(0.0117)	(0.0115)	(0.0015)	(0.0015)	(0.0002)	(0.0002)
Mother's Education (Years)		0.130***		0.123***		0.0099***		0.0002***
		(0.0015)		(0.0016)		(0.0002)		(5.73e-05)
Father's Education (Years)		0.158***		0.143***		0.0149***		6.61e-05
		(0.0020)		(0.0018)		(0.0003)		(4.91e-05)
Female		-0.113***		-0.106***		-0.0168***		0.0025***
		(0.0161)		(0.0159)		(0.0018)		(0.0003)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-Month of Birth FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	913,878	913,878	852,533	852,533	848,743	848,743	898,902	898,902
R-squared	0.340	0.414	0.356	0.425	0.162	0.201	0.010	0.010
Panel B. DHS / MIS / AIS								
	Death	Death	Death	Death	Death			
Temperature at Birth - 9	-0.0056***	-0.0056***	-0.0056***	-0.0053***	-0.0053***			
	(0.0015)	(0.0015)	(0.0015)	(0.0016)	(0.0016)			
Mother's Primary Edu +		-0.0094***						
		(0.0019)						
Mother's Secondary Edu +			-0.0108***					
			(0.0021)					
Wealth Index					-0.0013**			
					(0.0007)			
Year of Birth FE	Yes	Yes	Yes	Yes	Yes			
Region-Month of Birth FE	Yes	Yes	Yes	Yes	Yes			
Observations	86,915	86,915	86,915	90,130	90,130			
R-squared	0.0488	0.0491	0.0491	0.0491	0.0492			

Notes: In Panel A, the dependent variables are defined the same as in the corresponding Table 2-4 and A.2. Parental education variables are measure in years of schooling imputed from attainment. In Panel B, the sample contains mothers who gave birth in the two years preceding the interview. "Mother's Primary +" indicates that the mother's level of education is at least primary. "Mother's Secondary +" indicates that the mother's level of education is at least secondary. "Wealth Index" measures the wealth quintile of the individual. In both panels, standard errors, clustered at the region-month of birth level, are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table X: Temperature and Terminated Pregnancies in the DHS / MIS / AIS

	(1) Termination	(2) Termination	(3) Termination	(4) Termination	(5) Termination	(6) Termination
Demeaned Temperature at MRP - 3					-0.0021	-0.0021
					(0.0023)	(0.0023)
Demeaned Temperature at MRP - 2					-0.0036	-0.0035
					(0.0025)	(0.0025)
Demeaned Temperature at MRP - 1		-0.0038**	-0.0033**	-0.0064***	-0.0047**	-0.0048**
		(0.0016)	(0.0016)	(0.0023)	(0.0023)	(0.0023)
Demeaned Temperature at MRP					-0.0009	-0.0009
					(0.0023)	(0.0023)
Demeaned Temperature at MRP + 1					-0.0014	-0.0014
					(0.0020)	(0.0020)
Mother's Primary Edu +	0.0121***					0.0120***
	(0.0026)					(0.0028)
Wealth Index	0.0092***					0.0093***
	(0.0008)					(0.0009)
Region FE		Yes	Yes			
Year of Pregnancy FE	Yes	Yes	Yes	Yes	Yes	Yes
MRP FE			Yes			
Region-MRP FE				Yes	Yes	Yes
Observations	82,409	82,409	82,409	82,409	82,409	82,409
R-squared	0.0350	0.0328	0.0334	0.0705	0.0706	0.0728

Notes: The dependent variable is an indicator variable which takes the value of one if the woman reports that a pregnancy was terminated before birth for any reason. MRP is the first Month when the woman Reports being Pregnant. Demeaned Temperature at MRP - X refers to the demeaned temperature in Celsius degrees prevailing in the respondent's region X months before the interview. "Mother's Primary +" indicates that the mother's level of education is at least primary. "Wealth Index" measures the wealth quintile of the individual. Standard errors are in parentheses. In column (1), standard errors are robust. In columns (2) to (6), standard errors are clustered by Region-Month of pregnancy. *** p<0.01, ** p<0.05, * p<0.1.

Table XI: Temperature and Gender in the Census – 2 and Under

	(1) Female	(2) Female	(3) Female	(4) Female	(5) Female	(6) Female
Temperature at Birth - 15						-0.0013
						(0.0015)
Temperature at Birth - 14						-0.0005
						(0.0012)
Temperature at Birth - 13						0.0022*
						(0.0013)
Temperature at Birth - 12						-0.0012
						(0.0013)
Temperature at Birth - 11						-0.0003
						(0.0014)
Temperature at Birth - 10						-0.0020
						(0.0015)
Temperature at Birth - 9	-0.00115***	-4.93e-05	0.0005	0.0023**	0.0023**	0.0025**
	(0.0001)	(0.0010)	(0.0010)	(0.0011)	(0.0011)	(0.0012)
Temperature at Birth - 8						0.0011
						(0.0012)
Temperature at Birth - 7						0.0009
						(0.0012)
Temperature at Birth - 6						-0.0029**
						(0.0013)
Temperature at Birth - 5						-0.0001
						(0.0014)
Temperature at Birth - 4						0.0006
						(0.0013)
Temperature at Birth - 3						0.0014
						(0.0013)
Temperature at Birth - 2						-0.0002
						(0.0012)
Temperature at Birth - 1						-0.0005
						(0.0011)
Temperature at Birth						-0.0013
						(0.0012)
Temperature at Birth + 1						0.0019*
						(0.0011)
Temperature at Birth + 2						0.0007
						(0.0011)
Temperature at Birth + 3						0.0009
						(0.0010)
Precipitation at Birth - 9					-6.66e-06	
					(2.31e-05)	
Region FE		Yes	Yes			
Year FE		Yes	Yes	Yes	Yes	Yes
Month FE			Yes			
Region-Month FE				Yes	Yes	Yes
Observations	839,645	839,645	839,645	839,645	839,645	839,645
R-squared	0.000	0.000	0.001	0.007	0.007	0.007

Notes: The dependent variable is an indicator variable which takes a value of one if the individual is female. The sample is restricted to children who are less than two years old at the time of the interview. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. "Precipitation at Birth - 9" refers to the precipitation level nine months before birth measured in millimeters. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table XII: Temperature and Outcomes by Gender in the Census

	(1) Years of Schooling (Attainment)	(2) Years of Schooling (Direct)	(3) Literacy	(4) No Disability
Temperature at Birth - 9	0.109***	0.129***	0.0108***	0.0019***
	(0.0139)	(0.0136)	(0.0012)	(0.0002)
Female	0.329*	0.571***	0.0142	0.0164***
	(0.199)	(0.2030)	(0.0239)	(0.0018)
Female * Temp. at Birth - 9	-0.0620***	-0.0733***	-0.0053***	-0.0005***
	(0.0091)	(0.0094)	(0.0011)	(8.20e-05)
Year of Birth FE	Yes	Yes	Yes	Yes
Region-Month of Birth FE	Yes	Yes	Yes	Yes
Observations	3,640,483	3,464,871	3,600,947	3,620,457
R-squared	0.241	0.244	0.166	0.013

See Tables 2-4 and A.2 for descriptions of the dependent variables. The variable "Temperature at Birth - 9" refers to the temperature in Celsius degrees which prevails 9 months before birth. All regressions cluster at the region-month level. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Appendix

Table A.1: List of Surveys in the DHS / MIS / AIS

Country	Survey and Year
Angola	MIS/2006-07, MIS/2011
Benin	DHS/2001, DHS/2006
Burkina Faso	DHS/1998-99, DHS/2003
Burundi	DHS/2010
Cameroon	DHS/2004
Chad	DHS/2004
Congo Democratic Republic	DHS/2007
Côte d'Ivoire	AIS/2005
Ethiopia	DHS/2005, DHS/2011
Ghana	DHS/1998-99, DHS/2003, DHS/2008
Guinea	DHS/1999, DHS/2005
Kenya	DHS/2003, DHS/2008-09
Lesotho	DHS/2004-05, DHS/2009-10
Liberia	DHS/2006-07, MIS/2008-09, MIS/2011
Madagascar	DHS/2003-04, DHS/2008-09, MIS/2011
Malawi	DHS/2000, DHS/2004-05, MIS/2010
Mali	DHS/2001, DHS/2006
Mozambique	DHS/2003-04
Namibia	DHS/2000, DHS/2006-07
Niger	DHS/2006
Nigeria	DHS/1999, DHS/2003, DHS/2008, MIS/2010
Rwanda	DHS/2000, DHS/2005, DHS-Interim/2007-08, DHS-Special/2010
Senegal	DHS/2005, MIS/2006, MIS/2008-09, DHS/2010-11
Sierra Leone	DHS/2008
Swaziland	DHS/2006-07
Tanzania	DHS/1999, DHS/2004-05, AIS/2007-08, DHS/2009-10
Uganda	DHS/2000-01, DHS/2006, MIS/2009-10
Zambia	DHS/2001-02, DHS/2007
Zimbabwe	DHS/1999, DHS/2005-06, DHS/2010-11

Table A.2: Temperature and Years of Schooling Directly Reported in the Census

	(1) Years of Schooling	(2) Years of Schooling	(3) Years of Schooling	(4) Years of Schooling	(5) Years of Schooling	(6) Years of Schooling
Temperature at Birth - 15						0.0167
						(0.0128)
Temperature at Birth -14						0.0137
						(0.0140)
Temperature at Birth -13						-0.0066
						(0.0129)
Temperature at Birth -12						0.0050
						(0.0129)
Temperature at Birth -11						0.0106
						(0.0139)
Temperature at Birth - 10						0.0277**
						(0.0134)
Temperature at Birth - 9	0.0886***	0.0834***	0.0748***	0.0937***	0.0907***	0.0350**
	(0.0008)	(0.0074)	(0.0072)	(0.0139)	(0.0140)	(0.0138)
Temperature at Birth - 8						0.0320**
						(0.0130)
Temperature at Birth - 7						0.0185
						(0.0136)
Temperature at Birth - 6						0.0219*
						(0.0131)
Temperature at Birth - 5						-0.0056
						(0.0139)
Temperature at Birth - 4						0.0001
						(0.0112)
Temperature at Birth - 3						0.0024
						(0.0150)
Temperature at Birth - 2						0.0171
						(0.0131)
Temperature at Birth - 1						-0.0012
						(0.0149)
Temperature at Birth						0.00714
						(0.0153)
Temperature at Birth + 1						0.0323**
						(0.0140)
Temperature at Birth + 2						0.0333**
						(0.0153)
Temperature at Birth + 3						0.0388***
						(0.0125)
Precipitation at Birth - 9					-0.0004***	
					(0.0001)	
Region FE		Yes	Yes			
Year FE		Yes	Yes	Yes	Yes	Yes
Month FE			Yes			
Region*Month FE				Yes	Yes	Yes
Observations	3,464,871	3,464,871	3,464,871	3,464,871	3,464,871	3,464,871
R-squared	0.003	0.223	0.224	0.226	0.226	0.226

Notes: The dependent variable is the number of years of schooling reported directly from the individual. The variable "Temperature at Birth - X" refers to the temperature in Celsius degrees which prevails X months before birth. "Precipitation at Birth - 9" refers to the precipitation level nine months before birth measured in millimeters. All regressions cluster at the region-month level except for column (1), which reports robust standard errors. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.