Too hot to hold: the effects of high temperatures during pregnancy on birth weight and adult welfare outcomes

Hu, Zihan and Li, Teng

National University of Singapore, Department of Economics,
National University of Singapore, Department of Economics

1 January 2016

Too Hot to Handle: the Effects of High Temperatures during Pregnancy on Endowment and Adult Welfare Outcomes

Zihan Hu and Teng Li*

Department of Economics, National University of Singapore

version: January 1, 2016

Preliminary–Comments most welcome

Abstract

Exposure to high temperatures during pregnancy is generally associated with low birth weight—a proxy for endowment. But whether such early life shock is further related to welfare losses in adulthood is still unknown. Utilizing random temperature fluctuations across 123 counties in China, we examine the relationships between high temperatures during pregnancy and birth weight and later outcomes. One standard deviation of high temperature days during pregnancy triggers about 0.17 kilograms loss of birth weight, and further in adulthood 1.63 cm decrease in height and 0.86 years less of schooling. Health and intelligence outcomes are adversely affected as well. The impacts are concentrated in the first and third trimesters. Such effects should become part of the calculations of the costs of global warming. Back-of-the-envelope predictions suggest that at the end of the 21st century newborns on average weigh 54.36-210.44 grams less. And the losses in height and education years are 0.52-2.02 centimeters and 0.26-1.01 years, respectively. We also argue these patterns are more likely consistent with physiological effects than with income effects, because total precipitation and high temperatures in the growing season of one year before birth have no significant effects.

Keywords: High temperatures during pregnancy, birth weight, adult welfare outcomes, global warming

*Zihan Hu and Teng Li, Department of Economics, National University of Singapore, 1 Arts Link, Singapore 117570. Email: huzihan0716@gmail.com, liteng@u.nus.edu. We thank Alice Chen, Junhong Chu, Olivier Deschenes, John Ham, Jessica Pan, Ivan Png, Slesh Shrestha, Aloysius Siow, Changcheng Song, Xi Xiong, Junjian Yi and Klaus Zimmermann for providing or facilitating helpful comments.

1 Introduction

A growing literature studies the relationships between early life conditions and later outcomes (see Currie and Almond 2011 for a comprehensive review). Several influential studies have examined the consequences of early life shocks, such as influenza pandemic (Almond 2006), hurricanes (Currie and Rossin-Slater 2013), famine (Chen and Zhou 2007), and civil war (Bundervoet et al. 2009). They find those shocks have persistent and profound effects on well-beings in later life.

The unusual nature of those events, however, raises the concern about the generalizability (Maccini and Yang 2009; Almond and Mazumder 2011). A general early life shock may be more amenable to intervention by policy makers (Almond and Mazumder 2011). The present work extends the existing literature by investigating the effects of high temperatures during pregnancy—a typical variation in early life—on birth weight and later outcomes, including height, health, educational attainment, and cognitive abilities. To our best knowledge, we present the first evidence on the long-term persistent effects of ambient heat shock in prenatal period in economics literature.

Although the impacts of heat stress *in utero* on newborns are well documented in epidemiological literature, they are underemphasized in economics. One pioneer work is Deschenes et al. (2009). Using data from 49 states in US, they find that being exposed to days above 85°F during pregnancy declines birth weight significantly. However, as the authors claim, whether the effects on birth weight are further related to adult outcomes (e.g. human capital, health, etc.) is of importance but left unanswered. In addition, people in developing countries may be more vulnerable to climate change due to limit accessibility to avoidance behaviors such as air-conditioners (Feng et al. 2010; Brooks et al. 2005). This situation may amplify the impacts of high temperatures. For instance, each household in rural China owns only 0.12 air conditioning units even in 2009.[1]

In this study we examine the effects of hot temperatures on birth weight, health condition, educational attainment and cognitive abilities of Chinese born in rural areas between

[1]The figure is derived from *China Statistical Yearbook 2010.*

1952 and 1994.[2] Combining individual characteristics from China Family Panel Studies (CFPS) with weather information from China Meteorological Administration, we find large effects of high temperatures during pregnancy on birth weight. One standard deviation increase of number of high temperature days leads to 0.17 kilograms loss of birth weight (31.2 % standard deviation).[3] More importantly, hot weather during pregnancy further triggers significant adult welfare losses in multiple dimensions. Adults, who experienced one standard deviation more high temperature days (around 39 days) in prenatal period, turn out to be 1.63 centimeters shorter, 0.86 years less of schooling and 22.8% to 27.2% standard deviation less of test score and evaluated health. The impacts are concentrated in the first and third trimesters.

Such effects, however, have not been taken into account in the costs of global warming. Based on the climate projections provided by National Aeronautics and Space Administration (NASA), we then perform back-of-the-envelope predictions for birth and adult outcomes of individuals born in rural areas of China in 2100. Compared to newborns in 2000, *caeteris paribus*, babies born at the end of the 21st century weigh 54.36-210.44 grams less on average. Further, in adulthood the losses in height and education years are 0.52-2.02 centimeters and 0.26-1.01 years, respectively.[4]

We propose two hypotheses that explain why hot weather might affect birth weight. The first explanation draws on the evidence from medical and epidemiological research (see Strand et al. 2011 and Beltran et al. 2013 for an epidemiological review). A pregnant woman may be sensitive to heat stress because: (i) the capacity to lose heat by sweating is lessened due to the declined ratio of surface area to body mass; (ii) weight gain triggers more heat production; (iii) the core temperature increases with accumulated fat deposition; and (iv) because of the increased body composition and metabolic rate of fetus, maternal heat stress rises (Prentice et al. 1989; Wells and Cole 2002). Another possibility, referred as income effects, is that high temperatures influence crop yields (Schlenker and Roberts 2009), then further affect household resources and nutrition for

[2] The earlier weather information (before 1951) is not available.

[3] The effect on birth weight for individuals born in urban areas is not statistically and economically significant. We therefore focus on rural sample. See results section for detail.

[4] The magnitudes rest on the assumption—when global greenhouse gas emissions peak.

pregnant women in rural areas. Distinguishing the two possible channels is crucial for policy implications. Controlling weather conditions in last year growing season and during pregnancy simultaneously, we find that the latter has no significant effects on birth weight and other outcomes. These evidences suggest that our results are more likely consistent with physiological effects than with income effects.

From a broader perspective, our findings may add to the literature on explaining the positive correlation between latitude and economics development. Many scholars provide convincing evidences that economics activities are correlated with geography indirectly through historical channels (see Wacziarg and Spolaore 2013 for a review). Some studies, however, show alternative direct explanations to such phenomenon, e.g. a high burden of diseases (Sachs and Malaney 2002), and pests and parasites that thrive in hot climates (Masters and McMillan 2001). Based on our findings, we may provide another explanation that high temperatures affect newborn endowment, and further human capital which is crucial for economic development (Romer 1986).

The next section describes the data and variable definitions. Section III introduces the identification strategy. Section IV presents the main findings, while Section V discusses the possible channels behind the impacts, and implements robustness checks. We talk about implications of our results and conclude in section VI.

2 Data and descriptive analysis

2.1 Data source

Birth weight and welfare outcomes.—The birth weight data is obtained from China Family Panel Studies (CFPS) 2010, a nationally representative, annual longitudinal survey of Chinese communities, families, and individuals. Launched in 2010 by the Institute of Social Science Survey (ISSS) of Peking University, the CFPS baseline survey interviews 14,798 households from 635 communities, including 33,600 adults and 8990 children in 25 provinces.[5] The studies represent 95% of the total population of China (Xie 2012).

[5]The 25 provinces are Heilongjiang, Jinlin, Laioning, Hebei, Beijing, Tianjin, Shanxi, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Henan, Anhui, Hubei, Jiangxi, Guizhou, Chongqing, Hunan, Guangdong,

The studies provide ample information on demographic status, such as gender, birth place (county), date of birth (month and year), birth order, number of siblings, and parental characteristics, e.g. age, educational attainments, etc. Based on the information of date of birth, we define each individual's prenatal period as nine months before the birth, around 270 days in total.[6] The whole period is typically divided into three trimesters, each of which consists of three months.

Many adult outcomes are included in the survey as well, e.g., height, weight, health evaluation, years of schooling, intelligence evaluation, and math and word test scores. Three variables reflect individuals' physical conditions, i.e. height, Body Mass Index (B-MI), and health status evaluated by interviewers. Based on BMI information, we generate a dummy variable indicating underweight (BMI≤18.5), under which scenario people face a higher risk for health problems (WHO 2006).[7] Health status ranges from 1 to 7, representing from poor to excellent condition. For the sake of interpretation, it is standardized in our empirical analyses. During CFPS conduction, one interviewer is responsible for all objects in one county in general. Therefore, relative to self-reported health condition, the evaluated health status is more reasonably comparable within county. Cognitive abilities are measured by years of schooling, intelligence, and word and math test scores. Intelligence is also evaluated by interviewers and defined similar to evaluated health. In word and math tests designed by CFPS, respondents are required to figure out as many Chinese characters as possible and to solve basic math questions including arithmetic operation, exponents, logarithms, trigonometric functions, sequence, permutation and combination, etc.[8] The two test scores are standardized as well. To reflect individual's integrated cognitive abilities, we create a new variable—standardized total test score—by summing standardized math and word test scores up.

Guangxi, Yunnan, Shaanxi, Sichuan, and Gansu. Figure 1 in appendix shows the geographic distribution of the 25 provinces.

[6]Prenatal period is inevitably measured with error, as the exact birth date and gestational length information are not available. The nine-month gestation period definition is supported by Patel et al. (2004), finding the median gestational age at delivery is about nine months in Asians. Several robustness checks in discussion section suggest our estimations be not sensitive to such measurement error.

[7]As epidemiological literature suggests, high birth weight individuals grow up with a higher probability of being obesity, while low birth weight babies are more likely to be underweight (Singhal et al. 2003). Thus in our context, we focus on underweight cases.

[8]See CFPS(2010) user's manual for a detailed description.

Temperature and other weather conditions.—The weather data is from China Meteorological Administration, containing 854 weather stations across China. We assign one weather station, closest to the county center within the province, to each county. Counties without weather station within 100km are excluded. On average the distance between weather station and county center is about 35.72km, and the ninety-fifth percentile is only 79.35km. Using alternative acceptable matching radius such as 60km, 80km and 120km does not change the main results. [9]

To assess the influences of temperature in prenatal period, the key variable is defined as the number of days with daily maximum temperature higher than 85°F.[10] Hereafter we refer to simply as high temperature or hot weather days. In our sample, a representative rural pregnant woman is exposed to about 44 hot weather days out of nine months pregnancy period.

In analysis, we restrict the sample to individuals born in rural areas, covering 84.05% of original CFPS sample.[11]Since individuals in rural areas work outside intensively and have limit ways to avoid ambient heat such as air conditioner, they are more likely to suffer hot weather. We further drop those individuals born between 1959 and 1962, whose prenatal period is between the three-year Great Famine (1958-1961) in China, as the Great Famine could trigger welfare losses as well (Chen and Zhou 2007) and thus confound the temperature effects (Meng et al. 2015).[12] The remaining sample contains 1255 individuals in 123 counties across 25 provinces (see Figure A.1). [13] The 123 counties are matched to 109 weather stations.[14] Sample statistics are presented in Table 1.

[9]Corresponding results are summarized in the appendix from Table A.2 to Table A.4

[10]The definition for high temperatures is similar to Deschenes et al. (2009). Our results are robust to several different temperature thresholds. See discussion section for a detailed analysis.

[11]We utilize his or her mother's occupation to identify whether an individual is born in rural area. If one's mother is field crop worker, then the individual is classified into rural group. Given the massive rural-urban migration in the last two decades in China, this classification gives us a much larger sample size, compared to just using rural-urban status of the surveyed place.

[12]Our results are not sensitive to including those individuals born during the Great Famine.

[13]Most sample losses come from observations with missing birth weight. By regressing birth weight missing indicator on demographic status and all the fixed effects included in our main specification, we find individuals with missing birth weight are randomly distributed.

[14]Some weather stations are assigned to two adjacent counties.

2.2 Descriptive regional patterns

Were ambient heat stress during prenatal period an determinant of birth weight and further welfare outcomes, we would expect that individuals in warmer regions have lower birth weight and worse welfare outcomes. We depict the relationships between temperature, birth weight, and adult outcomes across provinces in this subsection.

Birth weight against temperature.—Figure 1 Panel (a) plots mean birth weight for each province against the number of high temperature days (>85°F) in a representative year. Relative to southern provinces (circle markers in Figure 1), ones in the north (square markers) suffer hot weather less frequently.[15] The regional pattern of birth weight is striking. Babies born in the southern provinces gain less weight in general. For perspective, Guangdong, Guangxi, and Fujian provinces, located in the southest China, are the warmest areas of China, around 100 days in a typical year with a maximum temperature higher than 85°F. Compared to a representative baby in China, ones born in these three provinces weigh less by 4.5%, 9.2%, and 9.7%, respectively.

Temperature against welfare outcomes.—Panel (b)-(d) in Figure 1 suggest that hot weather is further related to welfare losses in adulthood. Panel (b), (c), and (d) plot the mean height, years of schooling, and word test score, respectively, against the number of hot weather days across provinces.[16] Panel (b) shows that the warmer areas (lower latitudes in general), the more losses in height. This phenomenon that in China the higher the latitude is, the taller people are, is also documented by Buxton (2013). Our findings suggest that low birth weight caused by climate may explain this geographical distribution phenomenon of height to some extent. Panel (c) and (d) show similar regional patterns on schooling years and word test score, but with flatter slopes.

[15]We use official geographical dividing line—Huai RiverQin Mountains—to define northern and southern China provinces.

[16]The standards for health and intelligence evaluations in different provinces are likely to be varied, as interviewers are different across provinces. Thus we do not describe the relationships for health and intelligence evaluations. The fit line for math test score is rather flat, showing no obvious regional pattern.

3 Empirical framework

To exploit how high-temperature exopsure during pregnancy period affects birth weight and further adult outcomes, we employ the following specification:

$$Y_{ijmt} = \alpha + \beta HighTemp_{ijmt} + X_i\gamma + \mu_j + \mu_j * t + \lambda_t + \eta_m + \epsilon_{ijmt}. \quad (1)$$

Here, i references individual, j presents county, and birth month and year are denoted by m and t, respectively. The outcome variables, Y_{ijmt} are birth weight, low birth weight dummy (LBW, $< 2500g$) and welfare outcomes (height, underweight dummy, standardized health and intelligence evaluations, schooling years, and standardized math, word and total test scores). The variable of interest in equation (1) is $HighTemp_{ijmt}$, the number of hot weather days during the gestational period. We add a vector of individual characteristics, X_i, including gender, birth order, sibling numbers, and parental's age at delivery and educational attainments, to capture individual heterogeneity. To account for any time-invariant county level factors, we control for μ_j, a county fixed effect. The vector of county specific linear time trend, $\mu_j * t$, are further included, partialling out time varying characters associated with both dependent and independent variables and are trending linearly during the analysis period. λ_t and η_m represent birth year and month fixed effects, capturing common shock over years and seasonality pattern. ϵ_{ijmt} denotes random error term. To allow for autocorrelations within county, standard errors should be clustered at county level. But as in some cases two adjacent counties share the same weather information from one station, it is reasonable to cluster the standard errors at weather station level.

As suggested by epidemiological literature, high-temperature exposure in different trimesters may have heterogeneous effects on birth weight. In the following specification, we allow for such heterogeneity:

$$Y_{ijmt} = \alpha + \beta_1^{T1} HighTemp_{ijmt}^{T1} + \beta_1^{T2} HighTemp_{ijmt}^{T2} + \beta_1^{T3} HighTemp_{ijmt}^{T3} + X_i\gamma + \mu_j + \mu_j * t + \lambda_t + \eta_m + \epsilon_{ijmt}. \quad (2)$$

where the variables of interest, $HighTemp^{T1}_{ijmt}$, $HighTemp^{T2}_{ijmt}$, and $HighTemp^{T3}_{ijmt}$, are the number of hot weather days in each trimester. T1, T2, and T3 denote the first, second and third trimester, respectively.

4 Main Results

This section reports estimates of the effects of ambient heat stress during pregnancy on birth weight, and then later life well-beings such as height, health status, education years, and other cognitive abilities. Additionally, heterogeneous effects of temperature across trimesters on all outcomes are outlined.

4.1 Effect on birth weight

We begin our analysis by presenting the effect of ambient heat during pregnancy on birth weight in Table 2. In column (1) and column (2), we show the effect of high temperature days on birth weight and low birth weight incidence for the full sample (including the rural and urban individuals). We find that birth weight is 3.15 grams lower for one additional high temperature day. And the coefficient is statistically significant at 5 percent level. Correspondingly, the probability of LBW increases by 0.09 % percentage points although not statistically significant.

Next, the coefficients are presented for rural born (column (3)-(6)) and urban born (column (7)-(8)) individuals respectively. For the rural sample, one additional high temperature day declines the birth weight by 4.4 grams (significant at 1% level). The effects are not negligible. One standard deviation increase of high temperature days (38.91 days) leads to 171 grams drop of birth weight, which is about 30 percent standard deviation of birth weight.[17].In addition, it increases the risk for LBW by 5.8 percentage points. In contrast, high temperature days have no effects on birth outcomes for urban individuals statistically and economically, as can be seen in column (7) and (8). The comparison shows that the impacts shown in the full sample are primarily driven by individuals born

[17]Another concern is that these effects may be tail-driven. Therefore, we run another regression using the 1% winsorized birth weight. The coefficient of interest is 0.0083 and still significant at 1% level, similar to the main results.

in rural areas. This is possibly because living conditions, e.g. housing quality and cooling tools availability, in rural areas are much worse than those in urban areas in China. Plus, rural individuals, in general, work outside intensively and thus are directly exposed to ambient heat frequently. Therefore, we henceforth focus on the rural sample. [18]

Concerned about potential omitted variables, we conduct two additional tests to check the validity of the specification. If high temperature days are considerable random conditional on those fixed effects, the coefficient should remain unchanged by including demographic controls. The point estimates in column (4) and (6) are similar to those in column (3) and (5), respectively. As a more direct test, we regress high temperature days on individual characteristics with the exact same fixed effects as in the main specification. The coefficients for individual characteristics are far from significant. And the p-value of the joint significance test is 0.56, indicating no explanation power of those characteristics on high temperature days. The preceding analyses suggest that our results capture the causal effects of the high temperature days. [19]

We thus far define the high temperature as daily maximum temperature more than 85 °F. We do admit that this threshold is arbitrary to some degree. To test the sensitivity of the estimates to the temperature threshold, we apply different thresholds, ranging from 70 °F to 90 °F. The point estimates and 95% confidence intervals are plotted in Figure 2. The results turn out to be highly robust to different high temperature day definitions.

4.2 Effects on later outcomes

As we find significant effects of high temperature days on birth weight, a proxy of endowment, it is of great importance to know whether this loss in endowment is serious enough to trigger welfare losses in adulthood.

Table 3 shows negative impacts of ambient heat on physical related outcomes. High temperature days significantly decline height and evaluated health. One standard deviation increase of high temperature days lowers the height by 1.65 cm (20.8% standard

[18] Most of the results of later outcomes for urban sample are not significant.

[19] In Table A.1, we further include quadratic county-specific trend, province-season fixed effects, year-season fixed effects respectively. The coefficients of interest remain stable.

deviation), and decreases 23.0% standard deviation of evaluated health status. Although not statistically significant, it increases the likelihood of underweight slightly as well.

Besides health, high temperature days during pregnancy also have significant effects on cognitive abilities measured by schooling years, test scores and evaluated intelligence. The estimates in Table 4 show that one standard deviation increase of high temperature days lead to 0.82 years less of schooling and 15.6% reduction of evaluated intelligence. In addition, it induces 22.4% standard deviation decrease of total test score. Comparing column (4) and column (5) in Table 4, we can see that most of the losses in total test score come from declined word test score.

Next, we run the sensitivity checks by using different definitions of high temperature day. Figure 3 summarizes the coefficients and 95% confidence intervals for the estimates on height, evaluated health, schooling years and word test score using thresholds from 70°F to 90 °F, respectively. It can be seen that the effects of high temperatures during pregnancy are not sensitive to the temperature threshold.

By investigating the effects of ambient heat, we aim at exploiting a common shock during pregnancy. If heat adversely affected birth weight only beyond certain level accumulation of high temperature days, it would sabotage the external validity of our results as the great frequency of high temperature days is not that common. In other words, the presence of the non-linearity may change the welfare implications. Employing semi-parametric method, Figure 4 provides no support for the non-linear effects of high temperatures on birth weight and adult outcomes.[20] The birth weight, height, evaluated health, schooling years, and word and math test scores all decline almost linearly with the number of high temperature days.

Up to now, we focus on the effects of ambient heat, whereas cold weather may have impacts as well. Table A.5 in appendix shows that low temperature days defined as those with daily minimum temperature lower than 25 °F have no effects on birth weight and later outcomes. Moreover, including low temperature days in the regressions does not change the coefficients of high temperature days.

[20]See appendix—partially linear model—for the detail of the method of our semi-parametric regressions.

4.3 Trimester heterogeneity

In the subsequent analyses of this section, we allow for heterogeneous effects of ambient heat across trimesters. Table 5 illustrates the effects of high temperatures in each trimester. The column (1) indicates that the high temperature days in all three trimesters significantly decrease birth weight. Plus, the heat effects seem larger in the first and third trimesters on most outcomes. Although the differences between the first (or the third) and second trimesters are not statistical significant at traditional level, they are reasonably large. For perspective, the coefficient of high temperature days in the third trimester is -0.012, two times as large as that of in the second trimester (-0.006). The magnitudes of ambient heat effects in the first and third trimesters are close to each other.

This pattern is, to some extent, consistent across most of outcome variables, such as education years, math and word test scores, and underweight. The impacts of hot weather in the second trimester are not statistically significant different from zero. For all test scores, the coefficient differences between the first (or the third) and second trimesters are significant at 5% level.

5 Discussion

5.1 Physiologic vs. income effects

The results thus far have presented the effects of high temperatures during pregnancy on birth weight and adult outcomes. Two channels may account for such impacts. One possibility is that hot weather has adverse physiologic influences on pregnant women due to physical and mental strains.[21] By affecting the pregnant women's health condition, temperature further triggers negative impacts on newborns, e.g. low birth weight. In addition to physiologic effects, high temperatures also cause damage to crop yields (Schlenker and Roberts 2009; Burgess et al. 2011), which determine family resources in rural areas and further the quality of newborns through income effects suggested by Maccini and Yang (2009).[22] Should income effects matter, high temperatures and total precipitation in last

[21]For details, see introduction section

[22]Schlenker and Roberts (2009) find that above 32°C(=90°F) is harmful for cotton, corn, and soybeans.

year growing season then would significantly affect birth weight and potentially other adult outcomes. Moreover, the coefficients on high temperature days during pregnancy should fall due to partialling out income effects. To distinguish the two channels, we simultaneously control high temperature days during pregnancy, and high temperature days and total precipitation in last year growing season before birth in regressions for all outcomes.[23]

In Table 6, the definition of high temperature days in last year growing season is those with daily maximum temperature above 90°F, which is detrimental to crops. The first row in Table 6 shows that high temperature days in last year growing season before birth do not have significant effects on all outcomes except height, though all coefficients are negative. Log rainfall in the last year growing season before birth has no significant impacts on all outcomes either. The coefficients of high temperature days during pregnancy change slightly. The results provide no support for the existence of income effects before birth, consistent with the findings in Maccini and Yang (2009).

5.2 Temperature measurement error

Temperature information is from the weather station within the province closest to the birth place (county's centroid) in pregnancy period. But this measurement is only imperfectly correlated with the actual exposure, especially for those living far from the weather station. The classical measurement error, in our context, will make the negative effects of high temperatures on all outcomes underestimated. To fix the problem, we utilize the temperature information from the first, second, and third closest weather stations as instruments.[24]

IV estimates are presented in Table 7. Consistent with OLS estimates, coefficients on high temperature days in IV regressions are statistically significantly different from zero except for math test and underweight. We notice that the effects of high temperatures on height, health, and intelligence in IV estimates are larger than those in OLS estimates.

[23] Growing season is from April to September (Deschenes and Greenstone 2007).

[24] The IV estimates are still likely to be understated due to other measurement errors, such as unobserved length of gestational period and misreporting birth month.

The rest of the coefficients in IV estimates either similar to or slightly smaller than those in OLS.

To check the sensitivity of length of gestational period, we switch the nine-month period to eight-month one in regressions. Table 8 presents the effects of high temperature days in eight months before birth. We note that most estimates are still statistically significant. But the magnitudes of some coefficients decline modestly, possibly because the eight-month gestational period generates more measurement errors.

5.3 Placebo test

Finally, in Table 9, we run the same specifications as the main results section, but replace the variable of interest with the number of high temperature days in nine months one year before pregnancy.[25] For perspective, for an individual born in January 1970, his or her real prenatal period is from April to December 1969. Here we define the falsified pregnancy period from April to December 1968 to conduct a placebo test. Were birth weight and other outcomes affected by the mismatched weather, we would conclude that the weather condition may capture other unobserved factors affecting birth weight and adult outcomes. In Table 9, we find that in no case were the coefficients on high temperature days statistically significant or quantitatively meaningful.

6 Implications and concluding remarks

In this paper, we find ambient heat during pregnancy affects birth weight and increases the risk for low birth weight incidence. We then examine the impacts of high temperatures on height, weight, health status, education attainments, and other cognitive abilities. The results indicate that high temperature shocks in early life not only trigger adverse birth outcomes but have persistent and profound effects on later life. Suffering one additional standard deviation hot weather days *in utero* (38.91 days), individuals turn out to be 1.63 centimeters shorter, 0.86 years less of schooling, and 22.8% to 27.2% standard devi-

[25]Results are similar when we switch the variable with number of high temperature days two or three years before pregnancy.

ation less of test scores and evaluated health. Importantly we also examine the possible mechanisms behind such effects. As high temperature days and total precipitation during the growing season in the year before birth have negligible effects on both birth weight and later outcomes, we argue these patterns are more likely consistent with physiological effects than with income effects.

We take our estimated effects of high temperature days during pregnancy, namely the estimates reported in Table 2, 3, and 4 and conduct back-of-the-envelope calculations based on climate predictions by NASA, with a view to drawing implications from these results. NASA predicts downscaled climate scenarios for the globe by the General Circulation Model (GCM) conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5).[26] Two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs) are included—RCP 4.5 and 8.5.[27] The daily temperature predictions contain projections from 21 climate models and are error-corrected through comparisons performed against the historical data.[28] Our predictions hereafter rely on ACCESS1-0 model.[29]

Given greenhouse gas emissions peaking around 2040 (RCP 4.5 scenario), we predict that, holding all else equal, babies born in rural areas of China in 2100 on average will be weighted 54.36 grams less than those born in 2000 due to global warming. Further, those individuals in adulthood will suffer a 0.52-centimeter decrease in height and a 0.26-year less of schooling. In the pessimistic case (RCP 8.5 scenario), the birth weight loss rises sharply to 210.43 grams. Likewise, the losses in height and education years are 2.02 centimeters and 1.01 years, respectively. The above predictions are based on strong assumptions that all other related factors remain constant, i.e. the same purchasing power,

[26]The CMIP5 GCM is supported by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5).

[27]The RCPs are possible greenhouse gas concentration trajectories adopted by Intergovernmental Panel on Climate Change (IPCC). Specifically, RCP 4.5 presumes that global annual greenhouse gas emissions (measured in CO2-equivalents) peak around 2040, then decrease. In RCP 8.5, emissions keep increasing throughout the 21st century.

[28]The 21 models are ACCESS1-0, BCC-CSM1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CNRM-CM5, CSIRO-MK3-6-0, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, INMCM4, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M.

[29]The magnitude of predictions from other models are similar.

medical technologies, and family characteristics. As other factors are being improved in China, especially in rural areas, the effects of global warming may be alleviated.

References

Almond, D. (2006). Is the 1918 influenza pandemic over? long term effects of in utero influenza exposure in the post 1940 u.s. population. *Journal of Political Economy*, 114(4):672–712.

Almond, D. and Mazumder, B. (2011). Health capital and the prenatal environment: the effect of ramadan observance during pregnancy. *American Economic Journal: Applied Economics*, pages 56–85.

Beltran, A. J., Wu, J., and Laurent, O. (2013). Associations of meteorology with adverse pregnancy outcomes: a systematic review of preeclampsia, preterm birth and birth weight. *International journal of environmental research and public health*, 11(1):91–172.

Brooks, N., Adger, W. N., and Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global environmental change*, 15(2):151–163.

Bundervoet, T., Verwimp, P., and Akresh, R. (2009). Health and civil war in rural burundi. *Journal of Human Resources*, 44(2):536–563.

Burgess, R., Deschenes, O., Donaldson, D., and Greenstone, M. (2011). Weather and death in india. *Cambridge, United States: Massachusetts Institute of Technology, Department of Economics. Manuscript.*

Buxton, L. D. (2013). *The peoples of Asia*. Routledge.

Chen, Y. and Zhou, L.-A. (2007). The long-term health and economic consequences of the 1959–1961 famine in china. *Journal of Health Economics*, 26(4):659–681.

Currie, J. and Almond, D. (2011). Human capital development before age five. *Handbook of Labor Economics*, 4:1315–1486.

Currie, J. and Rossin-Slater, M. (2013). Weathering the storm: Hurricanes and birth outcomes. *Journal of Health Economics*, 32(3):487–503.

Deschenes, O. and Greenstone, M. (2007). The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *The American Economic Review*, pages 354–385.

Deschenes, O., Greenstone, M., and Guryan, J. (2009). Climate change and birth weight. *The American Economic Review*, pages 211–217.

Feng, S., Krueger, A. B., and Oppenheimer, M. (2010). Linkages among climate change, crop yields and mexico–us cross-border migration. *Proceedings of the National Academy of Sciences*, 107(32):14257–14262.

Maccini, S. and Yang, D. (2009). Under the weather: Health, schooling, and economic consequences of early-life rainfall. *The American Economic Review*, 99(3):1006–1026.

Masters, W. A. and McMillan, M. S. (2001). Climate and scale in economic growth. *Journal of Economic Growth*, 6(3):167–186.

Meng, X., Qian, N., and Yared, P. (2015). The institutional causes of china's great famine, 1959–1961. *The Review of Economic Studies*, page rdv016.

Patel, R. R., Steer, P., Doyle, P., Little, M. P., and Elliott, P. (2004). Does gestation vary by ethnic group? a london-based study of over 122 000 pregnancies with spontaneous onset of labour. *International journal of epidemiology*, 33(1):107–113.

Prentice, A., Goldberg, G., Davies, H., Murgatroyd, P., and Scott, W. (1989). Energy-sparing adaptations in human pregnancy assessed by whole-body calorimetry. *British journal of Nutrition*, 62(01):5–22.

Racine, J. (1997). Consistent significance testing for nonparametric regression. *Journal of Business & Economic Statistics*, 15(3):369–378.

Robinson, P. M. (1988). Root-n-consistent semiparametric regression. *Econometrica: Journal of the Econometric Society*, pages 931–954.

Romer, P. M. (1986). Increasing returns and long-run growth. *The journal of political economy*, pages 1002–1037.

Sachs, J. and Malaney, P. (2002). The economic and social burden of malaria. *Nature*, 415(6872):680–685.

Schlenker, W. and Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to us crop yields under climate change. *Proceedings of the National Academy of sciences*, 106(37):15594–15598.

Singhal, A., Wells, J., Cole, T. J., Fewtrell, M., and Lucas, A. (2003). Programming of lean body mass: a link between birth weight, obesity, and cardiovascular disease? *The American journal of clinical nutrition*, 77(3):726–730.

Strand, L. B., Barnett, A. G., and Tong, S. (2011). The influence of season and ambient temperature on birth outcomes: a review of the epidemiological literature. *Environmental research*, 111(3):451–462.

Wacziarg, R. and Spolaore, E. (2013). How deep are the roots of economic development? *Journal of Economic Literature*, 51(2):325.

Wells, J. C. and Cole, T. J. (2002). Birth weight and environmental heat load: a between-population analysis. *American journal of physical anthropology*, 119(3):276–282.

Xie, Y. (2012). The user's guide of the china family panel studies (2010). *Beijing: Institute of Social Science Survey, Peking University.*

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
Birth Weight (500 grams)	6.06	1.11	2	10
Low Birth Weight	0.07	0.25	0	1
Height (cm)	165.14	7.95	140	197
underweight	0.15	0.35	0	1
Word Test	0	1	-2.59	1.32
Math Test	0	1	-2.15	1.72
Education Years	8.01	3.68	0	20
Evaluated Health	0	1	-3.91	1.14
Evaluated Intelligence	0	1	-3.53	1.48
Age	26.19	8.63	16	58
Female	0.46	0.5	0	1
Mother's Education Years	3.36	3.81	0	12
Mother's Age at Birth	25.21	4.5	16	47
Father's Education Years	5.75	4.13	0	15
Father's Age at Birth	27.23	5.04	17	51
Birth Order	1.58	0.95	1	6
Number of Siblings	1.68	1.17	0	4
High Temp Days	44.49	38.91	0	177
High Temp Days (1st trimester)	12.41	19.95	0	88
High Temp Days (2nd trimester)	15.56	22.22	0	90
High Temp Days (3rd trimester)	16.51	23.27	0	88
N		1255		

Notes: The sample contains 1255 individuals in 123 counties across 25 provinces. All individuals of the sample are born in rural areas. High temperature days are defined as ones with daily maximum temperature higher than 85°F. For interpretation convenience, evaluated health condition, math and word test scores, and intelligence evaluation are standardized. 109 weather stations are assigned to the 123 counties. Under some cases, two adjacent counties share the data from the same weather station.

Table 2: The impacts of high temperatures during pregnancy on birth weight

	Full Sample		Rural Sample				Urban Sample	
Dependent Variable:	Birth Weight	LBW	Birth Weight		LBW		Birth Weight	LBW
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
High Temp Days	-0.0063**	0.0009	-0.0085***	-0.0088***	0.0015**	0.0015**	-0.0001	-0.0002
	(0.0024)	(0.0007)	(0.0031)	(0.0031)	(0.0007)	(0.0007)	(0.0074)	(0.0022)
Female	-0.2383**	0.0155		-0.2000*		0.0128	-0.3372	0.0151
	(0.0922)	(0.0139)		(0.1033)		(0.0172)	(0.2425)	(0.0402)
Mother's Education Years	0.0015	0.0010		0.0030		0.0005	0.0092	-0.0038
	(0.0080)	(0.0018)		(0.0118)		(0.0026)	(0.0334)	(0.0066)
Mother's Age at Birth	-0.0178	0.0021		-0.0027		0.0016	-0.0424	0.0018
	(0.0129)	(0.0022)		(0.0139)		(0.0021)	(0.0599)	(0.0057)
Father's Education Years	0.0105	-0.0012		0.0172		-0.0031	0.0142	0.0026
	(0.0087)	(0.0020)		(0.0112)		(0.0034)	(0.0309)	(0.0069)
Father's Age at Birth	0.0207*	-0.0026		0.0144		-0.0052*	0.0000	0.0110
	(0.0117)	(0.0025)		(0.0121)		(0.0030)	(0.0492)	(0.0079)
Birth Order	0.0153	0.0120		-0.0047		0.0194	0.4261	-0.0653
	(0.0543)	(0.0116)		(0.0551)		(0.0124)	(0.6529)	(0.1159)
Number of Siblings	-0.0899	-0.0155		-0.0958		-0.0156	-0.0363	0.0271
	(0.0581)	(0.0134)		(0.0676)		(0.0153)	(0.1997)	(0.0400)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1694	1694	1255	1255	1255	1255	439	439
R-Squared	0.376	0.285	0.371	0.385	0.283	0.291	0.708	0.693

Notes: For column (1) and column (2), an observation is an individual born in either rural or urban areas. For columns (3)-(6), the samples are restricted to rural born individuals. For column (7) and column (8), the sample are restricted to those urban born individuals. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Ordinary least squares estimates for all columns. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 3: The impacts of high temperatures on adult health conditions

Dependent Variable	(1) Height	(2) Underweight	(3) Health
High Temp Days	-0.0423***	0.0009	-0.0059***
	(0.0160)	(0.0012)	(0.0019)
Female	-10.4974***	0.0132	-0.1025
	(0.5170)	(0.0360)	(0.0938)
Mother's Education Years	0.1098	0.0042	-0.0097
	(0.0666)	(0.0057)	(0.0135)
Mother's Age at Birth	-0.0377	-0.0004	-0.0008
	(0.0723)	(0.0049)	(0.0148)
Father's Education Years	-0.0334	0.0033	0.0234**
	(0.0577)	(0.0051)	(0.0116)
Father's Age at Birth	0.0872	-0.0020	0.0086
	(0.0595)	(0.0042)	(0.0121)
Birth Order	0.2397	-0.0477	0.0101
	(0.3888)	(0.0309)	(0.0586)
Number of Siblings	-0.7753**	0.0572*	-0.0468
	(0.3709)	(0.0290)	(0.0657)
County FE	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes
Observations	1255	1255	1255
R-Squared	0.676	0.260	0.503

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. The dependent variables of column from (1) to (3) are height, underweight indicator (BMI≤18.5), and standardized evaluated health, respectively. Ordinary least squares estimates for all columns. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 4: The impacts of high temperatures on adult cognitive abilities

	(1) Education	(2) Intelligence	(3) Test(total)	(4) Wordtest	(5) Mathtest
High Temp Days	-0.0212**	-0.0040*	-0.0059**	-0.0073***	-0.0038
	(0.0092)	(0.0021)	(0.0030)	(0.0026)	(0.0034)
Female	-0.3158	-0.0047	-0.0615	-0.0240	-0.0916
	(0.2702)	(0.0825)	(0.0702)	(0.0722)	(0.0737)
Mother's Education Years	0.0593	-0.0086	0.0102	0.0028	0.0164*
	(0.0370)	(0.0097)	(0.0082)	(0.0079)	(0.0094)
Mother's Age at Birth	0.0477	-0.0048	-0.0017	-0.0094	0.0062
	(0.0443)	(0.0145)	(0.0120)	(0.0116)	(0.0129)
Father's Education Years	0.1333***	0.0173	0.0388***	0.0326***	0.0404***
	(0.0435)	(0.0108)	(0.0097)	(0.0093)	(0.0104)
Father's Age at Birth	-0.0493	0.0065	-0.0081	-0.0016	-0.0136
	(0.0475)	(0.0130)	(0.0110)	(0.0111)	(0.0111)
Birth Order	0.0916	-0.0089	0.0693	0.0828*	0.0475
	(0.2179)	(0.0913)	(0.0625)	(0.0473)	(0.0779)
Number of Siblings	-0.3231	-0.0197	-0.0865**	-0.0699*	-0.0929*
	(0.1957)	(0.0674)	(0.0427)	(0.0408)	(0.0475)
County FE	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes
Observations	1255	1255	1255	1255	1255
R-Squared	0.522	0.484	0.563	0.578	0.500

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. The dependent variables of columns (1) to (5) are schooling years, standardized math test score, standardized word test score, standardized total test score (combining word and math tests), and standardized evaluated intelligence, respectively. Ordinary least squares estimates for all columns. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 5: The impacts of high temperatures on birth weight and adult outcomes by trimester

Dependent Variable	(1) Birth Weight	(2) LBW	(3) Height	(4) Underweight	(5) Health	(6) Education	(7) Intelligence	(8) Test(total)	(9) Wordtest	(10) Mathtest
High Temp Days (1st trimester)	-0.0128***	0.0018*	-0.0264	0.0018	-0.0083**	-0.0386***	-0.0034	-0.0117***	-0.0122***	-0.0099**
	(0.0040)	(0.0010)	(0.0229)	(0.0016)	(0.0039)	(0.0138)	(0.0036)	(0.0040)	(0.0040)	(0.0041)
High Temp Days (2nd trimester)	-0.0061*	0.0009	-0.0463**	-0.0004	-0.0047**	-0.0096	-0.0028	-0.0015	-0.0033	0.0004
	(0.0034)	(0.0008)	(0.0217)	(0.0015)	(0.0020)	(0.0128)	(0.0028)	(0.0036)	(0.0031)	(0.0042)
High Temp Days (3rd trimester)	-0.0120**	0.0027*	-0.0490*	0.0036**	-0.0066*	-0.0341**	-0.0082**	-0.0118***	-0.0132***	-0.0090**
	(0.0052)	(0.0015)	(0.0285)	(0.0017)	(0.0035)	(0.0136)	(0.0034)	(0.0036)	(0.0037)	(0.0039)
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1255	1255	1255	1255	1255	1255	1255	1255	1255	1255
R-Squared	0.387	0.294	0.677	0.266	0.504	0.524	0.486	0.567	0.582	0.505
P-value (1st=2nd)	0.176	0.421	0.462	0.272	0.410	0.132	0.905	0.022	0.027	0.046
P-value (3rd=2nd)	0.167	0.160	0.945	0.035	0.634	0.182	0.198	0.019	0.027	0.036

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Each trimester includes three months. The dependent variables of columns (1) to (6) are birth weight, low birth weight incidence, height, underweight case (BMI≤18.5), standardized evaluated health, education years, standardized evaluated intelligence, standardized total test score, standardized math test score, and standardized word test score, respectively. Demographic controls include gender, birth order, number of siblings, and parents' education years and delivery age. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 6: The effects of precipitation and temperature in last year growing season before birth on all outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	Birth Weight	LBW	Height	Health	Education	Intelligence	Test(total)	Wordtest
HTD in Growing Season(-1)	-0.0169	-0.0020	-0.3798**	-0.0085	-0.0630	-0.0580	-0.0244	-0.0310
	(0.0417)	(0.0073)	(0.1706)	(0.0676)	(0.1720)	(0.0573)	(0.0323)	(0.0270)
Prec. in Growing Season(-1)	-0.0413	-0.0245	0.0146	-0.0678	-0.0515	0.0769	0.0200	0.0115
	(0.1587)	(0.0419)	(1.1353)	(0.1649)	(0.5080)	(0.2049)	(0.1320)	(0.1299)
High Temp Days	-0.0087***	0.0014*	-0.0414**	-0.0073***	-0.0212**	-0.0047*	-0.0059*	-0.0072***
	(0.0031)	(0.0007)	(0.0162)	(0.0022)	(0.0094)	(0.0024)	(0.0030)	(0.0027)
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1252	1252	1252	1252	1252	1252	1252	1252
R-Squared	0.378	0.300	0.680	0.507	0.517	0.495	0.562	0.579

Notes: An observation is an individual born in rural areas. HTD in Growing Season(-1) means the high temperature days (90°F) in the last year growing season. Prec. in Growing Season(-1) denotes log precipitation in the last year growing season. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Three observations are missed from the main regression sample as the weather information before their birth years is not available. Demographic controls include gender, birth order, number of siblings, and parents' education years and delivery age. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 7: The IV estimates of high temperatures on birth weight and adult outcomes

Dependent Variable	(1) Birth Weight	(2) LBW	(3) Height	(4) Underweight	(5) Health	(6) Education	(7) Intelligence	(8) Test(all)	(9) Wordtest	(10) Mathtest
High Temp Days	-0.0080***	0.0014**	-0.0528***	0.0007	-0.0081***	-0.0205***	-0.0062**	-0.0057**	-0.0073***	-0.0035
	(0.0028)	(0.0006)	(0.0147)	(0.0011)	(0.0020)	(0.0078)	(0.0024)	(0.0025)	(0.0022)	(0.0029)
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1252	1252	1252	1252	1252	1252	1252	1252	1252	1252
R-Squared	0.385	0.291	0.676	0.261	0.502	0.522	0.483	0.563	0.579	0.500

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. We use the weather information from the second and third closest weather stations as IVs to run 2SLS. Demographic controls include gender, birth order, number of siblings, and parents' education years and delivery age. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 8: The effects of high temperature during eight months before birth on all outcomes

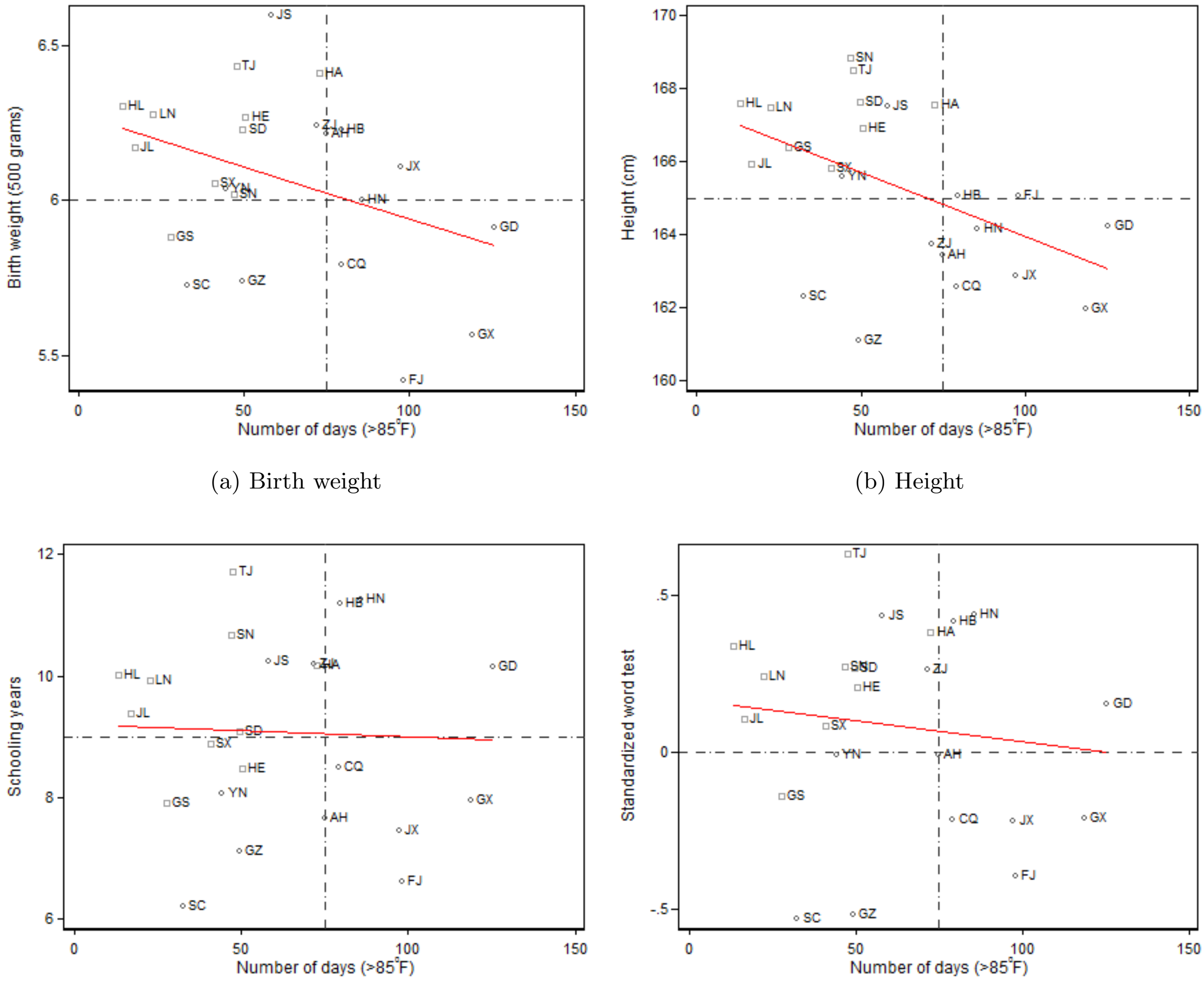
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	Birth Weight	LBW	Height	Health	Education	Intelligence	Test(total)	Wordtest
High Temp Days	-0.0065*	0.0014	-0.0455***	-0.0051***	-0.0176*	-0.0045**	-0.0052*	-0.0067***
	(0.0034)	(0.0008)	(0.0140)	(0.0015)	(0.0091)	(0.0020)	(0.0027)	(0.0022)
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1255	1255	1255	1255	1255	1255	1255	1255
R-Squared	0.382	0.291	0.677	0.502	0.521	0.485	0.562	0.578

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F within eight months before birth. Demographic controls include gender, birth order, number of siblings, and parents' education years and delivery age. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table 9: The effects of time period mismatched temperature information on all outcomes

Dependent Variable	(1) Birth Weight	(2) LBW	(3) Height	(4) Health	(5) Education	(6) Intelligence	(7) Test(total)	(8) Wordtest
High Temp Days (Year -1)	-0.0049	0.0010	0.0031	-0.0019	-0.0115	-0.0001	-0.0016	-0.0011
	(0.0035)	(0.0008)	(0.0185)	(0.0028)	(0.0109)	(0.0031)	(0.0030)	(0.0029)
Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1238	1238	1238	1238	1238	1238	1238	1238
R-Squared	0.388	0.321	0.673	0.501	0.521	0.488	0.567	0.583

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. The mismatched temperature information is the number of high temperature days in nine months one year before pregnancy. Demographic controls include gender, birth order, number of siblings, and parents' education years and delivery age. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.



(a) Birth weight (b) Height

(c) Education years (d) Word test score

Figure 1: Birth weight, adult outcomes against number of high temperature days (>85°F) in a typical year by province.

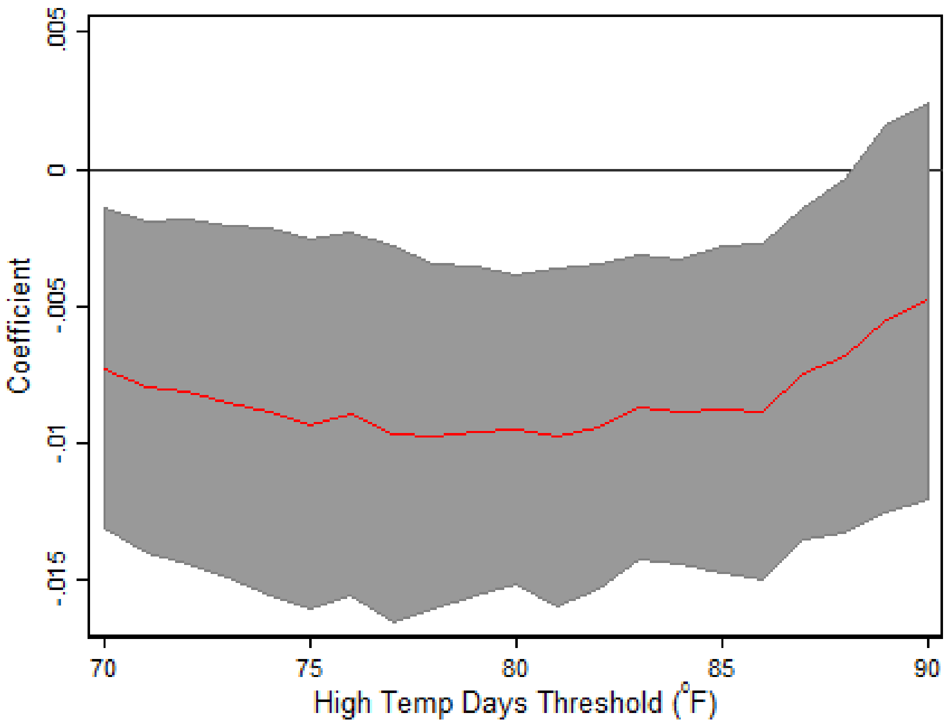
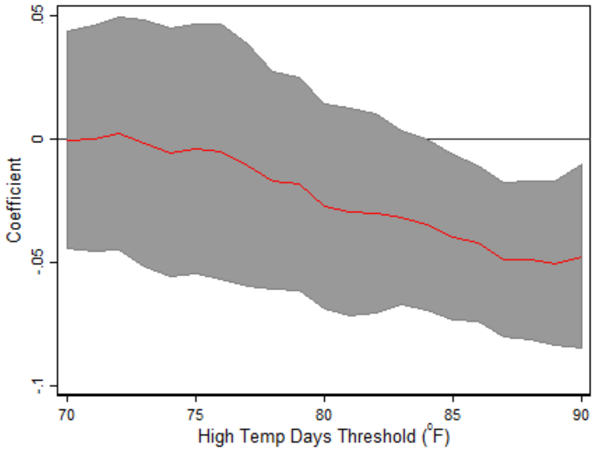
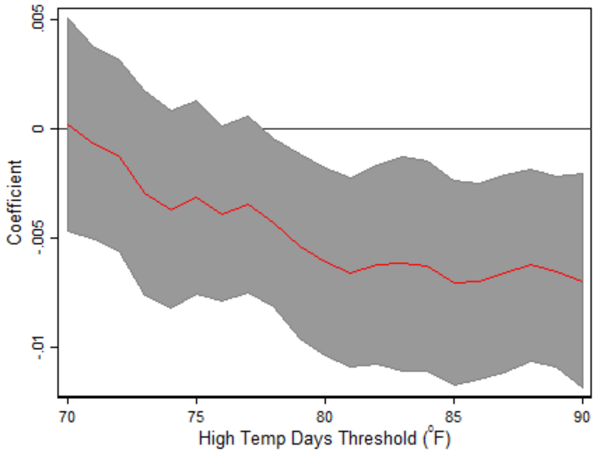


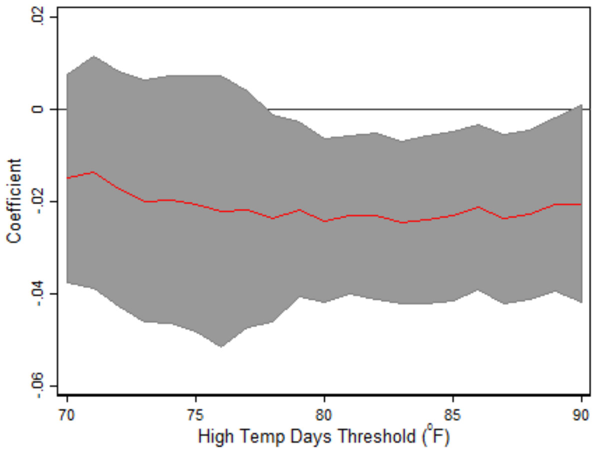
Figure 2: The coefficients of high temperature days (85°F) on birth weight (500 grams) from regressions using different definitions of high temperature. The red line denotes the point estimates on different high temperature days thresholds. The gray area presents 95% confidence interval.



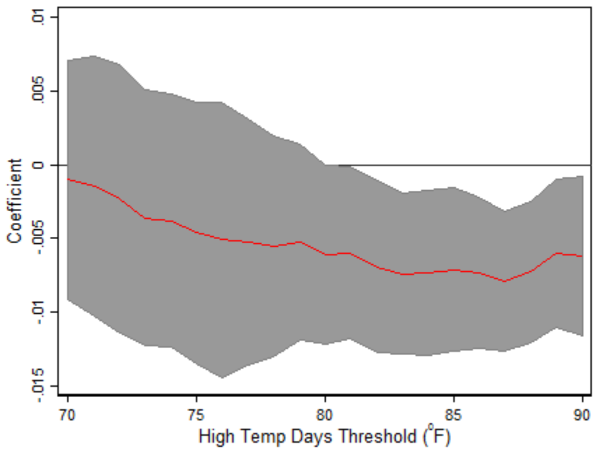
(a) Height



(b) Evaluated health

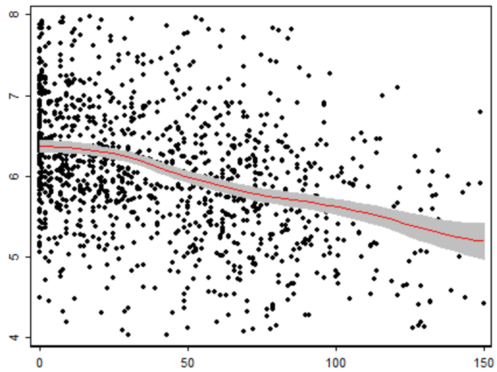


(c) Schooling years

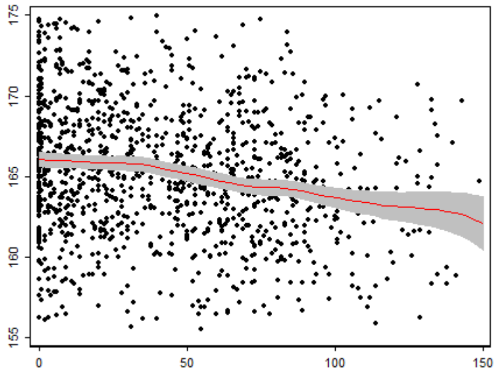


(d) Word test score

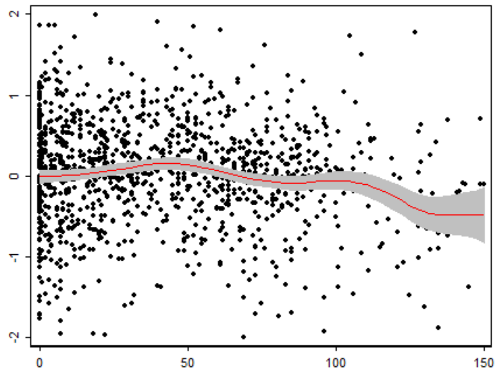
Figure 3: The coefficients of high temperature days (85°F) on adult outcomes from regressions using different definitions of high temperature. The red line denotes the point estimates on different high temperature days thresholds. The gray area presents 95% confidence interval.



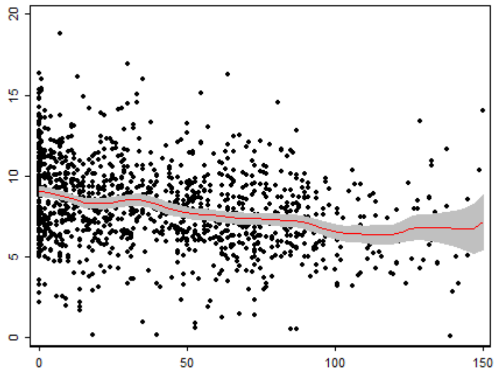
(a) Birth Weight



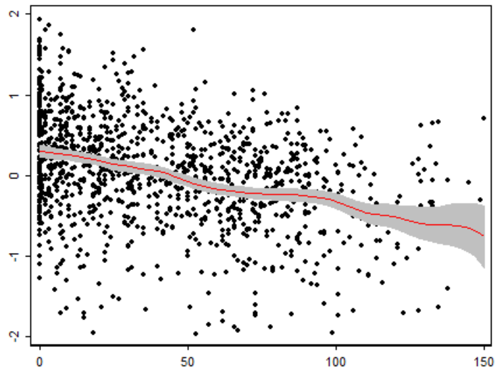
(b) Height



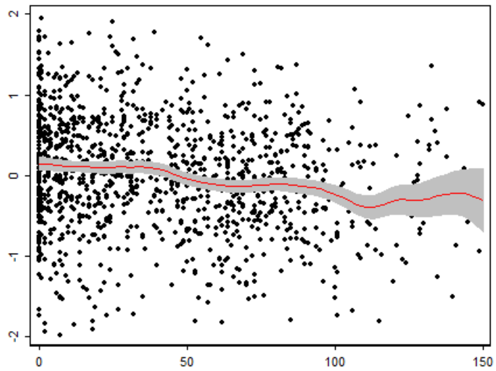
(c) Health



(d) Schooling years



(e) Word test score



(f) Math test score

Figure 4: High temperature days (85°F) during pregnancy against birth weight and adult outcomes. Specifications: The solid line shows fitted partially linear model, the gray area presents 95% confidence interval.

A Appendix

A.1 Partially linear model

In this subsection, we introduce the partially linear model employed in main results section. This model allows the key variable to be nonlinear:

$$Y_{ijmt} = f(X_{ijmt}) + Z\gamma + \epsilon_{ijmt}. \tag{3}$$

where X_{ijmt} represent the number of high temperature days during pregnancy. $f(.)$ is the unspecified nonlinear component, estimated by kernel regression with optimal bandwidth.[30] Z represent other controls and fixed effects in equation (1). To estimate the equation, we utilize Robinson difference estimator (Robinson 1988). As $E(\epsilon|X_{ijmt}, Z) = 0$ implies $E(\epsilon|X_{ijmt}) = 0$, we then have:

$$E(Y_{ijmt}|X_{ijmt}) = f(X_{ijmt}) + E(Z|X_{ijmt})\gamma. \tag{4}$$

Combining equation (3) and (4) yields

$$Y_{ijmt} - E(Y_{ijmt}|X_{ijmt}) = (Z - E(Z|X_{ijmt}))\gamma + \epsilon_{ijmt}. \tag{5}$$

The conditional moments are estimated by kernel regression. The OLS estimator of γ in equation (5) is $\sqrt{N}$-consistent and asymptotically normal. Equation (4) suggests

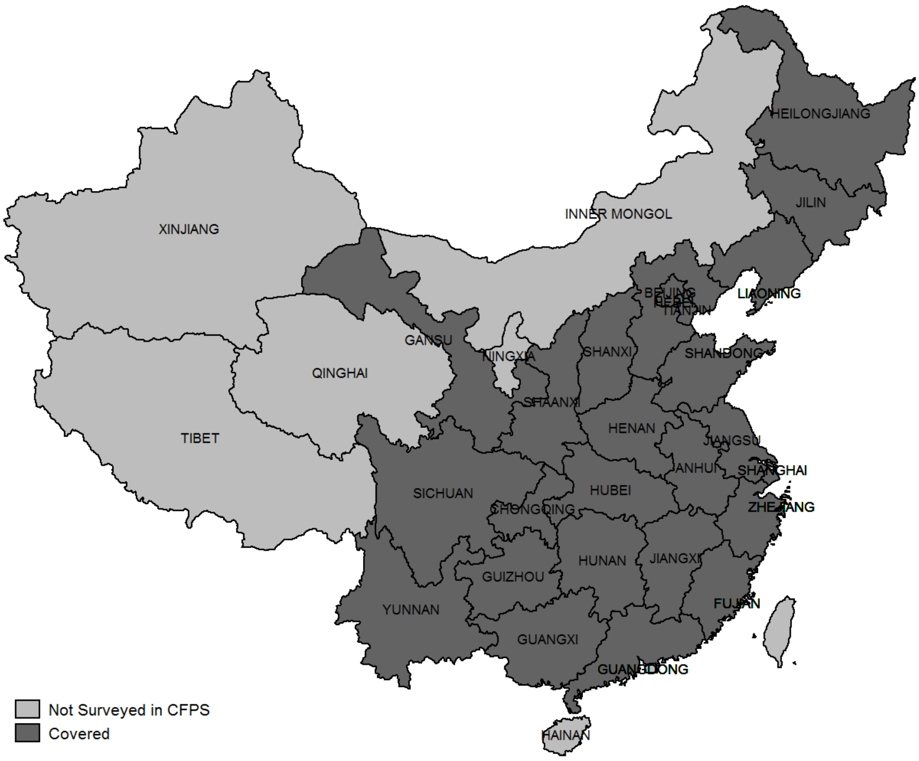
$$f(X_{ijmt}) = E(Y_{ijmt}|X_{ijmt}) - E(Z|X_{ijmt})\gamma. \tag{6}$$

Given estimated conditional moments and OLS estimates $\widehat{\gamma}$, $f(.)$ then can be consistently estimated by kernel regression. We further do the significance testing for nonparametric regression proposed by Racine (1997) to check the significant level of the nonparametric relationships.[31]

[30] Epanechnikov kernel function is applied here.

[31] The null hypothesis of the significance testing is $\frac{\partial E(Y_{ijmt}|X_{ijmt})}{\partial X_{ijmt}} = 0$, i.e the conditional mean of dependent variable is orthogonal to the variable of interest.

Figure 4 presents the birth weight estimate from equation (1). The y-axis represents the dependent variable partialled out from parametric fit. The relationship shown in the figure is striking. When number of high temperature days during pregnancy increases, birth weight drops monotonically. The marginal effects almost keep constant as temperature goes up. The significant testing shows that birth weight is not independent of ambient heat during pregnancy (p-value=0.00). Likewise, nonlinear effects are not obscure for adult outcomes, except evaluated health condition. The null hypotheses of the significance testing are rejected as well.



(a) Regression Sample

Figure A.1: The provinces covered in CFPS sample.

Table A.1: Robustness checks of the impacts of ambient heat in the prenatal period on birth weight with different specifications

	Dependent Variable: Birth Weight			
	(1)	(2)	(3)	(4)
High Temp Days	-0.0095***	-0.0113***	-0.0103**	-0.0118**
	(0.0034)	(0.0039)	(0.0042)	(0.0054)
Female	-0.2053*	-0.1414	-0.2316*	-0.1832
	(0.1145)	(0.1303)	(0.1372)	(0.1464)
Mother's Education Years	-0.0033	0.0001	-0.0034	-0.0021
	(0.0136)	(0.0167)	(0.0151)	(0.0176)
Mother's Age at Birth	-0.0021	-0.0085	0.0018	-0.0035
	(0.0154)	(0.0158)	(0.0175)	(0.0197)
Father's Education Years	0.0214*	0.0180	0.0210	0.0194
	(0.0129)	(0.0128)	(0.0143)	(0.0144)
Father's Age at Birth	0.0150	0.0193	0.0058	0.0102
	(0.0147)	(0.0157)	(0.0166)	(0.0179)
Birth Order	-0.0147	-0.0079	-0.0225	-0.0236
	(0.0609)	(0.0591)	(0.0695)	(0.0726)
Number of Siblings	-0.0826	-0.0858	-0.0419	-0.0330
	(0.0768)	(0.0816)	(0.0802)	(0.0853)
County FE	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes
County-specific Quadratic Trend	Yes	Yes	Yes	Yes
Province-Season FE	No	Yes	No	Yes
Year-Season FE	No	No	Yes	Yes
Observations	1255	1255	1255	1255
R-Squared	0.439	0.492	0.522	0.575

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table A.2: Robustness checks of the impacts of high temperatures on all outcomes using information from weather stations within 120 km radius

Dependent Variable	(1) Birth Weight	(2) LBW	(3) Height	(4) Health	(5) Education	(6) Intelligence	(7) Test(total)	(8) Wordtest
High Temp Days	-0.0088***	0.0015**	-0.0422***	-0.0070***	-0.0212**	-0.0048*	-0.0059**	-0.0073***
	(0.0031)	(0.0007)	(0.0161)	(0.0023)	(0.0092)	(0.0025)	(0.0030)	(0.0026)
Female	-0.1999*	0.0127	-10.4984***	-0.1218	-0.3167	-0.0055	-0.0614	-0.0238
	(0.1034)	(0.0172)	(0.5176)	(0.1116)	(0.2705)	(0.0989)	(0.0703)	(0.0722)
Mother's Education Years	0.0029	0.0005	0.1097	-0.0115	0.0592	-0.0103	0.0102	0.0028
	(0.0118)	(0.0026)	(0.0667)	(0.0160)	(0.0371)	(0.0116)	(0.0082)	(0.0079)
Mother's Age at Birth	-0.0027	0.0016	-0.0378	-0.0010	0.0476	-0.0057	-0.0017	-0.0094
	(0.0139)	(0.0021)	(0.0725)	(0.0176)	(0.0443)	(0.0174)	(0.0120)	(0.0116)
Father's Education Years	0.0172	-0.0031	-0.0330	0.0278**	0.1337***	0.0208	0.0388***	0.0326***
	(0.0112)	(0.0034)	(0.0578)	(0.0138)	(0.0436)	(0.0130)	(0.0097)	(0.0093)
Father's Age at Birth	0.0144	-0.0052*	0.0873	0.0102	-0.0493	0.0077	-0.0081	-0.0017
	(0.0121)	(0.0030)	(0.0596)	(0.0144)	(0.0475)	(0.0156)	(0.0110)	(0.0111)
Birth Order	-0.0051	0.0194	0.2384	0.0121	0.0906	-0.0112	0.0690	0.0826*
	(0.0552)	(0.0124)	(0.3893)	(0.0698)	(0.2182)	(0.1096)	(0.0626)	(0.0474)
Number of Siblings	-0.0962	-0.0155	-0.7743**	-0.0555	-0.3222	-0.0241	-0.0867**	-0.0701*
	(0.0676)	(0.0153)	(0.3704)	(0.0781)	(0.1958)	(0.0807)	(0.0427)	(0.0408)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1262	1262	1262	1262	1262	1262	1262	1262
R-Squared	0.385	0.291	0.676	0.503	0.522	0.484	0.563	0.579

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. Each county is matched to the nearest weather station within 120 kilometers from the same province. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%.

Table A.3: Robustness checks of the impacts of high temperatures on all outcomes using information from weather stations within 80 km radius

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	Birth Weight	LBW	Height	Health	Education	Intelligence	Test(total)	Wordtest
High Temp Days	-0.0100***	0.0013	-0.0461***	-0.0063**	-0.0207**	-0.0045	-0.0069**	-0.0085***
	(0.0034)	(0.0008)	(0.0152)	(0.0025)	(0.0100)	(0.0028)	(0.0033)	(0.0028)
Female	-0.1912	0.0131	-10.2840***	-0.1039	-0.2736	0.0200	-0.0648	-0.0325
	(0.1170)	(0.0183)	(0.4982)	(0.1175)	(0.2804)	(0.1026)	(0.0741)	(0.0766)
Mother's Education Years	0.0039	-0.0012	0.0903	-0.0218	0.0540	-0.0152	0.0120	0.0046
	(0.0127)	(0.0024)	(0.0626)	(0.0137)	(0.0390)	(0.0123)	(0.0085)	(0.0083)
Mother's Age at Birth	-0.0087	0.0016	-0.0670	-0.0069	0.0251	-0.0089	-0.0047	-0.0115
	(0.0125)	(0.0023)	(0.0692)	(0.0181)	(0.0416)	(0.0179)	(0.0125)	(0.0120)
Father's Education Years	0.0177	-0.0022	-0.0195	0.0300**	0.1366***	0.0217	0.0397***	0.0333***
	(0.0123)	(0.0036)	(0.0587)	(0.0147)	(0.0475)	(0.0141)	(0.0097)	(0.0093)
Father's Age at Birth	0.0194	-0.0056*	0.0810	0.0098	-0.0392	0.0077	-0.0093	-0.0039
	(0.0118)	(0.0032)	(0.0618)	(0.0151)	(0.0494)	(0.0164)	(0.0115)	(0.0113)
Birth Order	0.0152	0.0146	0.4031	0.0343	0.1428	0.0226	0.0790	0.0879*
	(0.0577)	(0.0127)	(0.3957)	(0.0705)	(0.2302)	(0.1182)	(0.0675)	(0.0504)
Number of Siblings	-0.1040	-0.0131	-0.9585**	-0.0600	-0.3369	-0.0407	-0.0868*	-0.0680
	(0.0755)	(0.0178)	(0.3834)	(0.0881)	(0.2164)	(0.0886)	(0.0459)	(0.0460)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1196	1196	1196	1196	1196	1196	1196	1196
R-Squared	0.393	0.297	0.693	0.503	0.536	0.473	0.583	0.601

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. Each county is matched to the nearest weather station within 80 kilometers from the same province. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%

Table A.4: Robustness checks of the impacts of high temperatures on all outcomes using information from weather stations within 60 km radius

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	Birth Weight	LBW	Height	Health	Education	Intelligence	Test(total)	Wordtest
High Temp Days	-0.0082**	0.0007	-0.0442**	-0.0068**	-0.0157*	-0.0068**	-0.0060*	-0.0082***
	(0.0034)	(0.0006)	(0.0183)	(0.0026)	(0.0087)	(0.0031)	(0.0032)	(0.0029)
Female	-0.2096	0.0215	-10.5086***	-0.0870	-0.1208	0.0738	-0.0458	-0.0061
	(0.1352)	(0.0204)	(0.4634)	(0.1318)	(0.2966)	(0.1093)	(0.0853)	(0.0869)
Mother's Education Years	0.0065	-0.0015	0.1072*	-0.0153	0.0507	-0.0165	0.0123	0.0059
	(0.0127)	(0.0027)	(0.0594)	(0.0129)	(0.0420)	(0.0133)	(0.0096)	(0.0099)
Mother's Age at Birth	-0.0095	0.0012	-0.0693	-0.0020	0.0417	-0.0076	-0.0031	-0.0077
	(0.0161)	(0.0027)	(0.0939)	(0.0230)	(0.0500)	(0.0228)	(0.0165)	(0.0166)
Father's Education Years	0.0097	-0.0021	-0.0088	0.0299**	0.1317***	0.0255	0.0402***	0.0312***
	(0.0117)	(0.0040)	(0.0599)	(0.0150)	(0.0474)	(0.0157)	(0.0103)	(0.0101)
Father's Age at Birth	0.0239*	-0.0043	0.0583	0.0056	-0.0453	0.0006	-0.0109	-0.0066
	(0.0125)	(0.0030)	(0.0697)	(0.0157)	(0.0561)	(0.0165)	(0.0144)	(0.0141)
Birth Order	-0.0272	0.0200	0.6821*	0.0555	0.1931	0.1054	0.0927	0.0983
	(0.0738)	(0.0153)	(0.3991)	(0.0809)	(0.2704)	(0.1177)	(0.0872)	(0.0667)
Number of Siblings	-0.0361	-0.0214	-1.0290**	-0.0324	-0.3020	-0.0906	-0.0863	-0.0770
	(0.0689)	(0.0187)	(0.4001)	(0.0915)	(0.2460)	(0.0975)	(0.0546)	(0.0536)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1096	1096	1096	1096	1096	1096	1096	1096
R-Squared	0.394	0.305	0.704	0.492	0.494	0.438	0.499	0.507

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. Each county is matched to the nearest weather station within 60 kilometers from the same province. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%

Table A.5: Horse-race regressions including low temperature days

Dependent Variable	(1) Birth Weight	(2) LBW	(3) Height	(4) Health	(5) Education	(6) Intelligence	(7) Test(total)	(8) Wordtest
High Temp Days	-0.0093***	0.0014*	-0.0409**	-0.0070***	-0.0210**	-0.0045*	-0.0055*	-0.0072**
	(0.0030)	(0.0007)	(0.0176)	(0.0024)	(0.0097)	(0.0025)	(0.0032)	(0.0028)
Low Temp Days	0.0025	0.0006	-0.0069	-0.0002	-0.0006	-0.0017	-0.0019	-0.0006
	(0.0033)	(0.0006)	(0.0171)	(0.0026)	(0.0107)	(0.0027)	(0.0029)	(0.0025)
Female	-0.1992*	0.0130	-10.4995***	-0.1218	-0.3160	-0.0062	-0.0621	-0.0242
	(0.1028)	(0.0172)	(0.5197)	(0.1114)	(0.2700)	(0.0988)	(0.0699)	(0.0720)
Mother's Education Years	0.0030	0.0005	0.1098	-0.0115	0.0593	-0.0103	0.0102	0.0028
	(0.0118)	(0.0027)	(0.0665)	(0.0160)	(0.0371)	(0.0116)	(0.0082)	(0.0079)
Mother's Age at Birth	-0.0026	0.0017	-0.0381	-0.0009	0.0476	-0.0059	-0.0018	-0.0094
	(0.0140)	(0.0021)	(0.0722)	(0.0176)	(0.0443)	(0.0173)	(0.0120)	(0.0116)
Father's Education Years	0.0177	-0.0030	-0.0348	0.0278**	0.1332***	0.0204	0.0384***	0.0325***
	(0.0111)	(0.0034)	(0.0580)	(0.0138)	(0.0436)	(0.0129)	(0.0096)	(0.0092)
Father's Age at Birth	0.0143	-0.0052*	0.0873	0.0102	-0.0493	0.0078	-0.0081	-0.0016
	(0.0121)	(0.0030)	(0.0591)	(0.0144)	(0.0475)	(0.0155)	(0.0109)	(0.0110)
Birth Order	-0.0042	0.0196	0.2383	0.0120	0.0915	-0.0110	0.0689	0.0827*
	(0.0542)	(0.0126)	(0.3908)	(0.0697)	(0.2174)	(0.1093)	(0.0624)	(0.0473)
Number of Siblings	-0.0963	-0.0157	-0.7739**	-0.0556	-0.3230	-0.0232	-0.0861**	-0.0698*
	(0.0673)	(0.0155)	(0.3716)	(0.0780)	(0.1949)	(0.0802)	(0.0425)	(0.0407)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Specific Linear Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1255	1255	1255	1255	1255	1255	1255	1255
R-Squared	0.386	0.292	0.676	0.503	0.522	0.484	0.563	0.578

Notes: An observation is an individual born in rural areas from 123 counties across 25 provinces. High temperature days are defined as ones with daily maximum temperature higher than 85°F. Low temperature days are defined as ones with daily minimum temperature lower than 25°F. Ordinary least squares estimates. Standard errors in parentheses, clustered by weather station. ***Significant at 1%, **significant at 5%, *significant at 10%