The Effects of Prenatal Exposure to Temperature Extremes on Birth Outcomes: The Case of China[+]

Xi Chen Chih Ming Tan Xiaobo Zhang Xin Zhang[*]

Abstract

This paper investigates the effects of prenatal exposure to extreme temperatures on birth outcomes – birth weight, small for gestational age, and birth defects – using nationally representative data from hospitals and clinics in rural China. During the span of our data (i.e., 1991-2000), indoor air conditioning was not widely available and migration was limited, allowing us to address identification issues endemic in the climate change literature related to adaptation and location sorting. We find substantial heterogeneity in the effects of extreme temperature exposure on birth outcomes. In particular, prenatal exposure to extreme cold has much stronger negative effects than exposure to extreme heat, suggesting a selection effect associated with extreme hot weather.

Keywords: Climate Change, Cold Weather, Heat Waves, Birth Weight, Birth Defects, Gestational Age, China

JEL Codes: I15; Q54; Q51

[+] Tan thanks the Greg and Cindy Page Faculty Distribution Fund for financial support. Chen is grateful for financial support by the Yale Macmillan Center Faculty Award. The authors acknowledge helpful comments by participants and discussants at the various conferences, seminars and workshops.
[*] Chen: Department of Health Policy and Management, Yale University, 60 College Street, P.O. Box 208034, New Haven, CT 06520-8034, USA. Tan: Department of Economics, College of Business and Public Administration, University of North Dakota, Gamble Hall, 293 Centennial Drive, Grand Forks, ND 58202-8369, USA. Xiaobo Zhang: National School of Development, Peking University, Beijing, 100871, China & International Food Policy Research Institute (IFPRI), 2033 K Street, NW, Washington, DC 20006, USA. Xin Zhang: National School of Development, Peking University, Beijing, 100871, China. Corresponding author (Xiaobo Zhang): x.zhang@cgiar.org.

1. Introduction

Climate change has induced more frequent yet largely unpredictable tail weather events, such as days of extreme temperatures (heat waves and arctic vortices), precipitation (flooding and drought), and windstorm variation (hurricanes) (IPCC 2014). In response to the increasing number of extreme weather events, there is a growing body of literature examining the impact of exposure to these events at various stages of the lifecycle.[1] In particular, *in utero* exposure to extreme temperatures has been shown to exert strong impacts on both birth and later life outcomes, including birth outcomes (Deschênes et al. 2009; Andalon et al. 2016; Ha et al. 2016; Hu and Li 2016), human capital accumulation, disabilities and infant mortality (Wilde et al. 2015), as well as adult depression symptoms (Adhvaryu et al. 2015).

In this paper, we investigate the effects of prenatal exposure to extreme temperatures on birth outcomes using a large representative dataset in China's National Disease Surveillance Points (DSPs) system. Our paper contributes to the literature in several dimensions. First, because the administrative records cover a wide range of regions with varying climatic conditions, it enables us to examine the effect of *in utero* exposure to either extreme high or low temperatures. Specifically, the detailed information on gestational age allows us to examine, following the seminal work by Deschênes et al. (2009), the number of days within each trimester of the gestational period during which a woman was exposed to either extreme cold or hot weather. Most previous studies primarily focus only on monthly mean temperature because of data availability.

Second, we are able to control for a range of other weather-related variables, which are often omitted in the previous literature. As Ziebarth et al. (2013) point out, due to the lack of large, high quality, and representative datasets (especially in developing

---

[1] A wide range of outcomes have been investigated, for example, birth outcomes (Currie and Rossin-Slater 2013), human capital formation (Graff Zivin et al. 2015), health, education and socioeconomic outcomes (Maccini and Yang 2009), hospitalizations (Ziebarth et al. 2013), the allocation of time (Graff Zivin et al. 2010), as well as mortality rate (Huynen et al. 2001; Deschenes and Moretti 2009; Deschênes and Greenstone 2011; Barreca 2012; Burgess et al. 2014; Barreca et al. 2015). Also see Graff Zivin et al. (2013), Dell et al. (2014) and Heal et al. (2015) for comprehensive surveys.

countries), some important controls for environmental and other confounders in studying the temperature effects on birth outcomes, such as humidity (Barreca 2012), are often omitted. To control for other weather-related confounders, we merge the DSP data with weather data from the National Oceanic and Atmospheric Administration (NOAA) which provides not only temperature data from 922 monitoring stations in China, but also includes a rich set of additional environmental controls, such as precipitation, visibility, dew point, wind speed, and fog.

Third, our study pays particular attention to birth defects, which have rarely been studied in the literature on the effects of *in utero* exposure to extreme weather. Our key outcome variables include not only birth weight and size for gestational age, which are commonly used in the literature, but also the prevalence of birth defects, a factor, that, to our knowledge, has yet to be examined.[2]

Fourth, importantly, we focus on the rural sample in order to exploit the institutional aspects that are unique to the Chinese context and inherent during the span of our data to circumvent the identification challenges associated with the *ex ante* and *ex post* coping mechanisms available to pregnant mothers and therefore better isolate the negative biological effect of temperature extremes.[3] For example, indoor air conditioning (AC) can be used as an *ex post* strategy to cope with hot weather. Barreca et al. (2016) find that, from 1960 onwards, there was a 70% decline in the mortality impact of days with mean temperatures exceeding 80 degrees Fahrenheit and virtually all of this decline can be explained by the diffusion of residential air conditioning. The diffusion of AC is not a concern in our sample period 1991-2000. There were as low as 1.32 air conditioning units per 100 households in rural China even by the end of 2000

---

[2] Currie and Rossin-Slater (2013) document the impact of maternal stress resulting from hurricanes on birth abnormalities. Currie et al. (2011) examine the impact of cleanups of hazardous waste sites on congenital anomalies. While Ha et al. (2016) study both extreme cold and hot temperatures on preterm birth, to our knowledge, this paper is the first to investigate the effects of extreme temperatures on birth defects.

[3] The biological effect identified in our paper results from impacts either through mother's elevated stress and worsening health or through agricultural productivity (measured by food quality, supply, and prices) which rural households generally rely for livelihoods and for food (Cornwell and Inder 2015; Andalon et al. 2016). However, the lack of information on agricultural activities for households covered by China's National Disease Surveillance Points (DSPs) prevents us from directly testing and distinguishing the relative importance of this agricultural channel from the maternal health channel.

according to China Statistical Yearbook (2001).

Another potentially serious threat to identification is the *ex ante* residential sorting. If concerned pregnant mothers migrate to regions with less temperature variation for the sake of their offspring's health, then we cannot confidently tell whether our findings on birth outcomes reflect differences in the unobserved characteristics of pregnant mothers in our treatment and control groups or the direct impact of *in utero* temperature exposure. The average rural pregnant mother's ability to engage in residential sorting is severely restricted in China by the residential registry (*hukou*) system in the 1980s and 1990s (Meng 2012).

Rural residents living in urban areas during the period of the data span would be faced with the choice of either accessing the private health care systems in urban areas – these were prohibitively expensive as the state medical insurance system did not cover private visits – or to receive primitive public medical services in their place of residence as defined by their *hukou*. Hence, though the late 1990's overlapped with the start of massive rural-to-urban migration in China, most rural would-be migrants had to stay in their hometowns to give birth as they could not afford to pay for child delivery in urban hospitals. Another reason why rural dwellers may not want to give birth in urban areas is because the one-child policy is more strictly monitored in urban areas.

In terms of our results, based on the matched dataset of birth records and daily prenatal temperature exposure, we find a linear relationship between low birth weight and temperature, where extremely cold days are associated with an increase in low birth weight. In particular, an additional day with a mean temperature below 25°F, relative to a day in the 45-65°F range, leads to an increase in low birth weight by 0.047 percentage points (or 1.57 percent of the mean incidence of low birth weight), and a day with a mean temperature above 85°F is associated with a decline in the probability of low birth weight by 0.032 percentage points (or 1.07 percent). We also find that exposure to extreme cold and hot weathers have differential impacts on birth defects. One more day with low temperature below 25°F leads to a significant increase in the probability of birth defects by 0.043 percentage points (or 4.30 percent) while exposure to an additional hot day above 85°F is associated with a statistically significant decline in the probability of birth defects by 0.061 percentage points (or 6.10 percent) relative to the reference temperature category.

The observed heterogeneity in exposure to cold weather versus heat waves can be explained by mortality selection *in utero*. Consistent with the seminal work of Trivers and Willard (1973) and a large body of studies that followed, our gender differentiated results suggest that male fetuses are more fragile than female fetuses in the wake of heat waves, resulting in heightened male mortality. Largely due to access to traditional indoor heating in rural China in the 1990s, extreme cold weather does not result in excess mortality (culling effect), but it leaves a scarring effect on the surviving children, in particular females. We also find that southerners have higher tolerance for heat, while northerners are more tolerate of cold. Since technological adaptation devices (i.e., air conditioning) were not widely available during the time period of our sample, this difference in temperature tolerance likely reflects evolutionary adaptation.

Finally, our paper also contributes to several other strains of thought in the health and development literature. Our emphasis on *in utero* exposure to environmental stressors on birth outcomes relates to work on the "fetal origins" (Barker 1992) of life health outcomes (Almond and Currie 2011). This literature suggests that early exposure to stressors such as malnutrition (Meng and Qian 2009; Tan, Tan, and Zhang 2015), family income shocks (Adhvaryu et al. 2014), and maternal stress (Persson and Ross-Slater 2014) have both short- and long-term effects on offspring.

More broadly, our work relates to a class of new family investment models by James Heckman and coauthors (Cunha et al. 2010; Heckman and Mosso 2014) that examine parental investment responses to initial child disadvantages. These models emphasize the importance of reinforcing and compensatory responses in the perpetuation of initial shocks on future outcomes. By quantifying the initial burden of one consequence of climate change (more frequent exposure to extreme temperatures) in a developing country context, our work aids in the ongoing efforts in this literature to quantify the barriers to global development posed by climate change.

The rest of the paper is organized as follows. We describe our data and empirical methodology in sections 2 and 3, respectively. We present our baseline and robustness results in section 4. Section 5 concludes.

2. Data

The birth record data was collected by China's National Disease Surveillance Points (DSPs) system. The DSP system includes 145 sites benchmarked against the 1990 China Census to represent China's variation in wealth and geographic dispersion. Data are reported monthly by the hospitals and clinics. The digitized data files are transmitted to the Chinese Academy of Preventive Medicine. The data contain demographic information on the child, including the exact date and county of birth, sex, birth weight, birth defects, birth order and gestational week.[4] The data also provide demographic information on the parents, including their age at the birth of the child, ethnicity, education and occupation. Table A1 presents summary statistics for these characteristics. The gestational age determines the date of conception and divides the pregnancy into three trimesters. Specifically, we assign weeks 1-13 to trimester 1, weeks 14-26 to trimester 2, and weeks 27-birth to trimester 3. We focus primarily on the rural subsample, which includes 312,568 observations for birth weight and 331,886 for birth defects from 31 provinces during 1991-2000.

The weather data is provided by the National Climatic Data Center (NCDC) under the National Oceanic and Atmospheric Administration (NOAA) of the United States. It contains consecutive daily weather records of 922 monitoring stations in China during 1973-2014. In addition, the longitudes and latitudes of monitoring stations are available. The key variable for our analysis is the daily mean temperature. The dataset also provide a rich set of climate controls, such as mean precipitation, visibility, dew point, wind speed, and the number of fog days (Table A1).[5]

To merge the birth data with the weather data, we calculate the weighted average values of all the monitors within 60 km to the centroids of each DSP county where the weights are equal to the inverse of distance between monitors and the county centroids.

---

[4] Figure A1 plots the distribution of gestational week in our sample.

[5] Air pollution data in China during 1991 to 2000 are not available. We use visibility and the number of fog days to proxy air quality. Atmospheric researchers show visibility as a reasonably good predictor of air pollution in China (Lee and Sequeira 2001; Qiu and Yang 2000; Cheung et al. 2005; Deng et al. 2008).

When a county has no stations within 60 km, we match the county to the nearest station within 200 km.[6]

Figure 1 displays the spatial distribution of DSPs and weather stations. The weather stations are evenly distributed in China and can be well matched with DSPs. Figure 2 depicts the distribution of daily mean temperature during the gestation period in our sample across five temperature bins, i.e., lower than 25°F bin, higher than 85°F bin, and three 20°F-wide bins in between. The vertical axis represents the average number of days that an expectant mother spends in each temperature bin while pregnant. The average number of days is 84.4 for the 45-65°F range, 11.2 for the less than 25°F bin and 11.7 for the greater than 85°F bin. In the subsequent analysis, the number of days in each temperature bin is calculated separately for each trimester of the gestation period to allow for substantial flexibility and nonlinear relationships between birth outcomes and temperature exposure.

3. Methodology

Our baseline econometric specification is as follows:

$$Y_{ict} = \sum_{TR=1}^{3}\sum_{j=1}^{5}\alpha_j^{TR} TEMP_{ctj}^{TR} + \sum_{TR=1}^{3}\beta^{TR} W_{ct}^{TR} + \phi X_{it} + \delta_c + \eta_t + \gamma_p \times year_t + \varepsilon_{ict}\,, \qquad (1)$$

where the dependent variable Y_{ict} is the birth outcome of child i in county c born at date t. The three birth outcomes we test in the paper are indicators for low birth weight (i.e., less than 2,500 grams), small for gestational age (SGA), and birth defects.[7] The key variables of interest $TEMP_{ctj}^{TR}$ are the number of days in the temperature bin j (from 1 to 5) during the trimester TR (from 1 to 3) of the gestational period for children born to county c and date t. We set the 45-65°F temperature bin as the reference group in all estimations. The vector X_{it} contains a set of demographic variables, including the child's gender, birth order, gestational age, mother's age and its square, dummies for mother's

---

6 The same approach is taken by Ziebarth et al. (2013). Our matching radius is comparable to those used in Deschenes et al. (2009) and Deschenes and Greenstone (2011). The indicator for fog days is matched with the nearest station.

7 The variable "small for gestational age (SGA)" refer to babies who are smaller in size than normal for the gestational age, defined as a weight below the 10th percentile for the gestational age.

education, occupation and ethnicity. We also control for a vector of rich weather conditions W_{ct}^{TR}, involving mean precipitation, visibility, dew points, wind speed and the number of fog days measured at the trimester level. δ_c is the county fixed effect, η_t is the birth month fixed effect, $\gamma_p \times year_t$ denotes the province-by-year fixed effect, and ε_{ict} is the error term.

By conditioning on the full set of fixed effects listed above, α_j^{TR} are identified using county-specific deviations in temperature from the county averages after controlling for seasonality and province-specific annual shocks. Due to the unpredictability of weather fluctuations, it is reasonable to assume that this variation is orthogonal to unobserved determinants of birth outcomes. To account for the correlation of mean county temperatures, standard errors are clustered at the county level.

4. Results

4.1. Baseline Results

Throughout this section, our main estimation results are visualized in Figures 3 through 5, while the full numerical results are presented in Tables A2 through A3.

Our baseline findings are presented in Figure 3 that plots the estimates associated with each temperature bin ($TEMP_{ctj}^{TR}$) on the three birth outcomes. Specifically, the panels A, B, and C in Figure 3 provide estimated impacts for, respectively, low birth weight, SGA, and birth defects. The reference (left-out) temperature bin in all our analyses is the 45-65°F bin. Hence, the plotted coefficients can be interpreted as the estimated effects of an additional day in the corresponding temperature bin during the gestational period on birth outcomes relative to the reference temperature category. The 95 percent confidence intervals are included in all panels in Figure 3.

Panel A of Figure 3 indicates a strong (linear) negative relationship between low birth weight and temperature, where low temperature increases the probability of low birth weight. Specifically, an additional gestational day with a mean temperature below 25°F, instead of a day in the 45-65°F range, is associated with an increase in the probability of having low birth weight by 0.047 percentage points (1.57 percent of the mean incidence of low birth weight in the sample), while an additional gestational day with a mean temperature above 85°F, relative to the reference temperature bin, leads to a decline in the probability of having low birth weight by 0.032 percentage points (1.07 percent). Both estimates are statistically significant at the 1% level. Because having low birth weight can also be a result of a child being born preterm, we also employ a SGA indicator to take into account the possibility of the child being small for gestational age. Panel B of Figure 3 shows that exposure to an additional cold day below 25°F results in a statistically significant (at the 1% level) increase in the probability of SGA by 0.070 percentage points (0.78 percent of the mean incidence of SGA in the sample).

The incidence of birth defects, which has been less studied in the literature, is another birth outcome we pay attention to. Similar to low birth weight, there is a linear relationship between the incidence of birth defects and temperature (Panel C of Figure 3). In particular, an additional day of exposure to the lowest temperature bin (<25°F) leads to a marginally significant (at the 10% level) increase in the probability of birth defects by 0.043 percentage points (4.30 percent of the mean incidence of birth defect in the sample), while gestational exposure to an additional hot day (with temperatures>85°F) is associated with a statistically significant (at the 5% level) decline in the probability of birth defects by 0.061 percentage points (6.10 percent) relative to the reference temperature category.

Finally, we also examine if the timing of exposure to extreme temperatures during pregnancy has any heterogeneous effects. Figure 4 plots the estimated coefficients associated with each temperature bin by trimester for low birth weight, SGA, and the incidence of birth defects, respectively. Same as our previous analysis, the reference (i.e., left out group) temperature bin is 45-65°F, therefore the coefficient estimates are interpreted as effects of an additional day in a particular temperature bin and trimester relative to the reference temperature category of 45-65°F.

We find similar effects in Figure 4 as we did in our benchmark case above (Figure 3) across the three trimesters for all three birth outcomes. For all three trimesters, an additional day of exposure to extreme cold (i.e., the lowest temperature bin) is associated with a statistically significant increase in low birth weight, SGA, and the incidence of birth defects. For SGA and birth defects, the point estimates suggest that exposure to extreme cold results in the greatest damage when the exposure occurs in the 1st trimester. However, for the case of low birth weight, exposure in the 3rd trimester seems to have the largest negative impact. We perform a Wald test to check the significance of differentiated effects across trimesters. For the low birth weight, the effects of relative low temperature (25-45°F) are significantly different between trimester 2 and trimester 3 at 5% significance level, while the effects of hot days (above 85°F) are distinguished between trimester 1 and trimester 2 at 5% significance level. For birth defects, the significant difference only occurs between trimester 2 and trimester 3 with relative high temperature (65-85°F) exposure. There is no significant difference in effect sizes across trimesters for SGA.

4.2. Placebo Test

We now detail findings from a falsification test which provides some assurance that our identifying assumptions are valid. Following and extending the strategy in Bharadwaj et al. (2014), we employ a placebo test whereby the treatment (i.e., the temperature bin variables, in our case[8]) is matched to trimesters out of the range of actual exposure for each woman, including three trimesters before conception and three trimesters after birth. Figure 5 presents the results. The left part of each panel plots the estimated coefficients with 95% confidence intervals associated with each temperature bin when matching temperature exposure in trimesters before conception. The right part is drawn based on the estimates after birth. The middle part replicates the baseline results in Figure 3 for ease of comparison. Neither pre-conception exposure nor postnatal exposure to extreme temperatures should affect low birth weight, SGA, or birth defects, unless the identified effect is driven by unobserved confounding factors or trends. Our results affirm the maintained hypothesis that the "false" treatment, in fact, did not have any effect on actual birth outcomes and indicate that our empirical strategy is effective in identifying the causal impact of temperature exposure on birth outcomes.

[8] The treatment variable in the case of Bharadwaj et al. (2014) has to do with pollution exposure.

4.3. Heterogeneous Effects and Mechanism Tests

To explain our heterogeneous findings for exposure to cold weather versus heat waves, we examine a number of potential mechanisms behind the observed relationship between extreme temperatures and birth outcomes. Specifically, exposure to heat waves may be associated with better birth outcomes (at least compared to exposure to extreme cold) through three potential channels.[9]

4.3.1. Selection into conception during heat waves based on socioeconomic status (SES)

The first possibility is that heat waves may affect fertility patterns, for example, through falling sexual activity during heat waves (Buckles and Hungerman 2013; Barreca et al. 2015; Wilde et al. 2015). The effect may be disproportionally larger for parents of low socioeconomic status (SES) if they are unable to shield against heat waves. Consequently, fertility may fall faster among lower SES families nine months after the heat wave, thereby raising the average SES among the pool of women conceiving children during heat waves. Naturally children from more privileged backgrounds with fitter mothers are more likely to have better birth outcomes during heat waves.

Given the universally low rate of air conditioning ownership among the rich and the poor in rural China in the 1990s, it is unlikely that this channel alone could explain the positive link between heat waves and birth outcomes. Nevertheless, we directly test differences in SES between those exposed to heat waves and those who were not at conception. While information on parental characteristics in the DSP data is limited, parental education serves as a good proxy for their SES. Table 1 tests two temperature specifications. The first (see, Panel A of Table 1) uses mean temperature in the month of conception, while the second specification (see Panel B of Table 1) more flexibly divides daily temperatures in the conception month into five bins. Figure A2 further

[9] Several studies also document the positive effects of heat waves at various stages of the lifecycle. For example, Wilde et al. (2015) find that higher temperature at conception leads to better educational attainment and literacy, fewer disabilities and lower child mortality. Andalon et al. (2016) find a positive and statistically significant association between APGAR scores and the most extreme definition of high-temperature shocks (events two or more SDs above the historical mean).

plots the coefficients from regressions of parental education on ten monthly mean temperatures during pregnancy.

Our results do not suggest any selection into conception during heat waves based on parental education. We simply cannot reject the hypothesis that there is no temperature-induced selection effect based on parental education level. While there is some evidence (see, Column (4) of Table 1) that more educated women are more likely to choose to start pregnancy when they are exposed to cold weather (i.e. less than 25°F), there is little evidence that they tend to be selected into pregnancy during heat waves. Overall, our results lend little support to the idea that differences in parental characteristics may drive the observed positive correlation between temperature at conception and birth outcomes.[10]

Heat waves may also potentially affect fertility patterns. For example, the rate of unintended conception may be lower during a heat wave (Wilde et al. 2015). In this setting, children conceived during heat waves may tend to be more wanted by their parents who are then therefore more likely to engage in remedial interventions and investments in them. This behavior by parents would then offset the biological effect of exposure to heat waves and explain the positive link between heat waves and birth outcomes. We have already shown that this is no selection into conception based on SES, but perhaps there are other reasons for children conceived during heat waves being better valued by their parents.

Unfortunately, we are not able to directly test this possibility due to a lack of information on actual pregnancy termination. Instead, we can use some indirect evidence to dismiss this channel. There is a strong preference for sons in Chinese culture. We would expect to see such a preference persist or even intensify in wake of heat waves. However, the results in Column (5) of Table 1 show that, if anything, higher mean temperatures during conception are associated with a higher probability of giving birth to girls rather than boys.

Overall, our baseline results cannot be explained by the story of purposed parental

[10] We have also controlled explicitly for parental education, age, occupation and ethnicity throughout the analyses in this paper to mitigate the potential biases due to parental selection.

selection.

4.3.2. In utero mortality selection as a result of exposure to heat waves

A second potential explanation is mortality selection *in utero*. Heat waves may increase fetal mortality directly through an adverse, direct biological effect or indirectly through reduced farm income, poor nutrition and maternal health. Mortality selection may work beyond the point of conception and explain the positive link in all trimesters (Figure 4). This hypothesis implies that during heat waves weaker fetuses are more likely to be selected out through the *culling effect*, while stronger fetuses tend to survive and are inherently healthier. We will observe positive associations between heat waves and birth outcomes when the *culling effect* dominates *scarring effect* on the surviving babies. Several papers provide evidence about this channel. For example, Wilde et al. (2015) attributes the positive correlation between temperature at conception and later life outcomes largely to fetal selection.

Farmers in China often have at least some access to traditional forms of winter heating (e.g. burning firewood or coal but no centralized winter heating) while they typically have very limited options to protect against heat waves. Better access to heating than cooling may help explain the negative impact of exposure to extreme cold weather (dominated by the scarring effect) and the positive impact of exposure to heat waves (dominated by the culling effect) in Figure 3 and Figure 4.

There is some evidence for the mortality selection hypothesis. First, as Column (6) of Table 1 shows, additional days during the conception month spent in heat waves (temperatures above 85°F) are statistically significantly (at the 1% level) associated with a lower number of births at the county level, while more days spent in extreme cold (temperatures below 25°F) are associated with higher birth numbers (at the 10% significance level).

Mortality selection due to exposure to poor conditions is gender differentiated. Trivers and Willard (1973) and a large number of scholars who subsequently wrote on this issue illustrate that male fetuses require more maternal resources to grow than female fetuses and tend to be more fragile. Thus, sex ratios may be skewed toward females through heightened male mortality even when male and female fetuses face the same exposure. Consistent with these studies, we find that babies born nine months after heat waves are more likely to be females (see, Column (5) of Table 1), indicative of intensified fetal loss during periods of extreme heat, especially because son preference is so prevalent in China that the male to female sex ratios at birth are much higher than one.

We also report evidence of heterogeneity in the effect of temperature exposure on birth outcomes between males and females (Table A4). The results in Table A4 are consistent with the fetal loss story that the negative effect of cold weather on birth outcomes is significantly larger for females. This is presumably because cold weather reaches the mortality cut-off for males but not for females as the latter are generally stronger *in utero*. Therefore, female fetuses demonstrate a larger scarring effect when exposed to cold weather. On the other hand, heat waves may reach the mortality cut-offs for both males and females, possibly resulting in a larger net impact of culling and scarring for females than males.

4.3.3. Non-technological adaptation

Finally, it may be that our baseline results simply reflect a composition effect based on multiple subpopulations who have inherent evolutionary (or, other non-technological) adaptation towards extreme temperatures. Table A5 shows results for our benchmark specification but allows for heterogeneity in the outcomes for counties in the North and South. There is some evidence that people who live in the North are better adapted to living in colder environments while those living in the South are better adapted at living in warmer climates. For example, Columns (1) through (3) and Columns (4) through (6) of Table A5 show that, in terms of low birth weight and SGA, Southerners do comparably better than Northerners when faced with extreme heat compared to when they experience extreme cold.

However, our findings for birth defects (see Columns (7) through (9) of Table A5) suggest that this inherent adaptation effect probably works at least to some degree with the mortality selection effect discussed in the above section. Babies who experience more days of extreme heat *in utero* and are born to Northerners have a lower incidence of birth defects, while those who experience more days of extreme cold have a higher incidence of birth defects. This suggests that northerners are more adaptable to cold weather than hot weather. When exposed to extreme heat *in utero*, the culling effect trumps the scarring effect for northerners.

5. Conclusion

In this paper, we investigate the consequences of *in utero* exposure to extreme temperatures (both extreme cold and heat waves) on birth outcomes; i.e., low birth weight, SGA, and the incidence of birth defects, using a large, nationally representative dataset collected by hospitals and clinics in China. We find that *in utero* exposure to extreme cold is more damaging to surviving children than exposure to heat waves, probably due to stronger mortality selection during hot periods. Lack of access to technological adaption devices against heat, e.g., air-conditioning, is a major cause of higher mortality selection in the event of heat waves. The northerners seem to be more vulnerable to heat waves, while southerner are more sensitive to extreme cold weather.

The existing literature has largely focused on the economic burden imposed by greater frequency of heat waves due to climate change on vulnerable populations. In a very narrow sense, our findings suggest some cause for optimism. In China, there is generally sufficient access to technologies that insulate families from cold (though not heat). Hence, the burden from exposure to extreme cold, while statistically significant, is not substantively economically burdensome in terms of magnitude (as our findings show). Since AC has become more readily available to rural population, the negative impact of heat waves is probably more muted than during our sample period 1990-2000.

However, an important caveat is that due to mortality selection (the culling effect) during heat waves, our identified impact of heat waves on birth outcomes focuses only on survivors. Our results should be interpreted as lower bound effects. When excess mortality is factored in, the total cost would be higher.

REFERENCES

Adhvaryu, Achyutu, James Fenske, Namrata Kala, and Anant Nyshadham. 2015. "Fetal Origins of Mental Health: Evidence from Africa." Mimeo.

Almond, Douglas and Janet Currie. 2011. "Killing Me Softly: The Fetal Origins Hypothesis." *Journal of Economic Perspectives* 25 (3): 153-172.

Andalon, Mabel, Carlos Rodríguez-Castelán, Viviane Sanfelice, João Pedro Azevedo and Daniel Valderrama. 2016. "Weather Shocks and Health at Birth in Colombia." *World Development*, 82: 69-82.

Barker, David J. P. 1992. "The Fetal Origins of Adult Hypertension." *Journal of Hypertension* 10: 39-45.

Barreca, Alan. 2012. "Climate Change, Humidity, and Mortality in the United States" *Journal of Environmental Economics and Management,* 63, 19-34.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. 2016. "Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century." *Journal of Political Economy* 124(1): 105-159.

Barreca, Alan, Olivier Deschenes, and Melanie Guldi. 2015. "Maybe Next Month? Temperature Shocks, Climate Change, and Dynamic Adjustments in Birth Rates." NBER Working Paper 21681.

Bharadwaj, Prashant, Mathew Gibson, Joshua Graff Zivin, Christopher A. Neilson. 2014. "Gray Matters: Fetal Pollution Exposure and Human Capital Formation." NBER Working Paper 20662.

Buckles, KS. and DM. Hungerman. 2013. "Season of Birth and Later Outcomes: Old Questions, New Answers." *The Review of Economics and Statistics* 95(3): 711-724.

Burgess, R., O. Deschenes, D. Donaldson and M. Greenstone. 2014. "The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India." Working paper. London: London School of Economics and Political Science.

Cheung, Hing-Cho, Tao Wang, Karstern Baumann and Hai Guo, 2005, "Influence of Regional Pollution Outflow on the Concentrations of Fine Particulate Matter and Visibility in the Coastal Area of Southern China," *Atmospheric Environment*, 39: 6463-6474.

Cornwell, K. and Inder, BA. 2015. Child Health and Rainfall in Early Life. *Journal of Development Studies* 51(7): 865–880.

Cunha. Flavio, James J. Heckman and Susanne M. Schennach. 2010. "Estimating the Technology of Cognitive and Noncognitive Skill Formation." *Econometrica* 78 (3): 883-931.

Currie Janet, Michael Greenstone and Enrico Moretti. 2011. "Superfund Cleanups and Infant Health." *American Economic Review: Papers & Proceedings*, 101: 3, 435-441.

Currie, Janet, and Maya Rossin-Slater. 2013. "Weathering the Storm: Hurricanes and Birth Outcomes." *Journal of Health Economics,* 32, 487-503.

Deng, Xuejiao, Xuexi Tie, Dui Wu, Xiuji Zhou, Xueyan Bi, Hanbo Tan, Fei Li and Chenglin Jiang, 2008, "Long-term Trend of Visibility and Its Characterizations in the Pearl River Delta (PRD) Region, China," *Atmospheric Environment*, 42: 1424-1435.

Deschenes, Olivier. 2014. "Temperature, Human Health, and Adaptation: A Review of the Empirical Literature." *Energy Economics,* 46: 606-619.

Deschenes, Olivier, and Enrico Moretti. 2009. "Extreme Weather Events, Mortality, and Migration." *The Review of Economics and Statistics,* 91(4): 659-681.

Deschenes, Olivier, and Michael Greenstone. 2011. "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US." *American Economic Journal: Applied Economics,* 3, October, 152-185.

Deschenes, Olivier, Michael Greenstone, and Jonathan Guryan. 2009. "Climate Change and Birth Weight." *American Economic Review: Papers & Proceedings,* 99(2): 211-217.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2014. "What Do We Learn from the Weather? The New Climate-Economy Literature." *Journal of Economic Literature,* 52(3): 740-798.

Graff Zivin, Joshua S., and Mathew Neidell. 2010. "Temperature and the Allocation of Time: Implications for Climate Change." *Journal of Labor Economics,* 32(1).

Graff Zivin, Joshua S., and Mathew Neidell. 2013. "Environment, Health, and Human Capital." *Journal of Economic Literature,* 51(3): 689-730.

Graff Zivin, Joshua S., Solomon M. Hsiang, and Mathew Neidell. 2015. "Temperature and Human Capital in the Short- and Long-Run." NBER Working Paper 02138.

Ha, S., D. Liu, Y. Zhu, S. S. Kim, S. Sherman and P. Mendola. 2016. "Ambient Temperature and Early Delivery of Singleton Pregnancies." Forthcoming, *Environmental Health Perspectives*.

Heal, Geoffrey, and Jisung Park. 2015. "Goldilocks Economies? Temperature Stress and the Direct Impacts of Climate Change." NBER Working Paper 21119.

Heckman, James J. and Stefano Mosso. 2014. "The Economics of Human Development and Social Mobility." *Annual Review of Economics* 6: 689-733.

Hu, Zihan, and Teng Li. 2016. "Too Hot to Hold: the Effects of High Temperatures during Pregnancy on Birth Weight and Adult Welfare Outcomes." MPRA Paper No. 68631.

Huynen, Maud M.T.E., Pim Martens, Dienke Schram, Matty P. Weijenberg, and Anton E. Kunst. 2001. "The Impact of Heat Waves and Cold Spells on Mortality Rates in the Dutch Population." *Environmental Health Perspectives,* 109(5): 463-470.

IPCC. 2014. *Climate change 2014: synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. technical report. Geneva: Intergovernmental Panel on Climate Change.

Lee, YL. and R. Sequeira. 2001. "Visibility Degradation across Hong Kong: Its Components and Their Relative Contributions" *Atmospheric Environment* 35: 5861–5872.

Maccini, Sharon, and Dean Yang. 2009. "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall." *American Economic Review,* 99(3): 1006-1026.

Meng, Xin. 2012. "Labor Market Outcomes and Reforms in China." *Journal of Economic Perspectives*, 26 (4): 75–102.

Meng, Xin and Nancy Qian. 2009. "The Long Term Consequences of Famine on Survivors: Evidence from a Unique Natural Experiment Using China's Great Famine." NBER Working Paper No. 14917.

Persson, Petra and Maya Rossin-Slater. 2014. "Family Ruptures and Intergenerational Transmission of Stress." IFN Working Paper No. 1022.

Qiu, Jinhuan and Liquan Yang, 2000, "Variation Characteristics of Atmospheric Aerosol Optical Depths and Visibility in North China during 1980-1994," *Atmospheric Environment*, 34: 603-609.

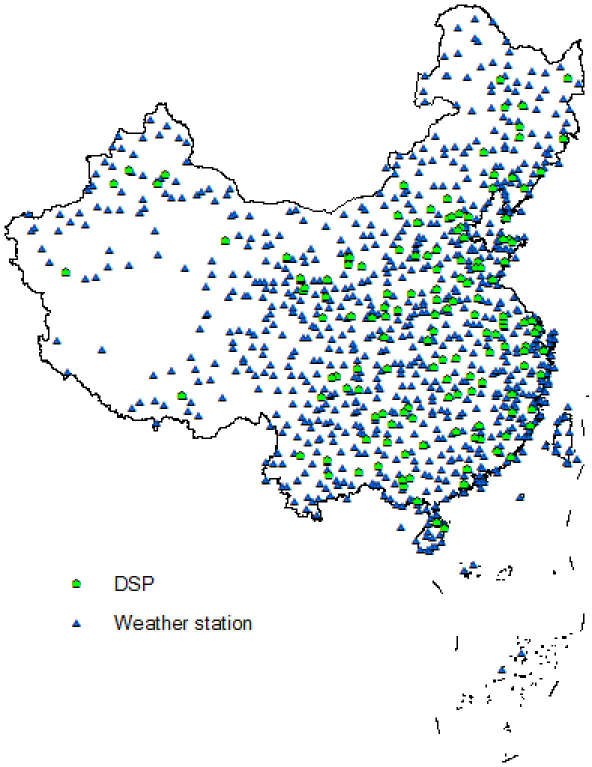
Tan, Chih Ming, Zhibo Tan and Xiaobo Zhang. 2015. "Sins of the Fathers: The Intergenerational Legacy of the 1959-61 Great Chinese Famine on Children's Cognitive Development." Available at SSRN: https://ssrn.com/abstract=2409452.

Trivers, R. L. and D. E. Willard. 1973. "Natural Selection of Parental Ability to Vary the Sex Ratio of Offspring," *Science* 179 (4068): 90–92.

Wilde, Joshua, Benedicte Apouey, and Toni Jung. 2015. "Heat Waves at Conception and Later Life Outcomes." Mimeo.

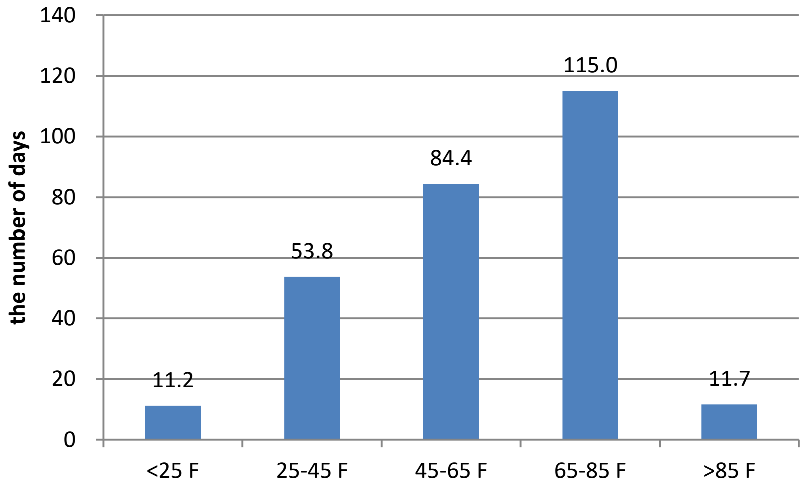
Ziebarth, Nicholas R., Maike Schmitt, and Martin Karlsson. 2013. "The Short Term Population Health Effects of Weather and Pollution: Implications of Climate Change." IZA Discussion Paper No. 7875.

Figure 1: Distribution of DSPs and weather stations



Source: China's National Disease Surveillance Points system; National Climatic Data Center, National Oceanic and Atmospheric Administration.
Note: This figure is plotted using ArcMap 10.3.1.

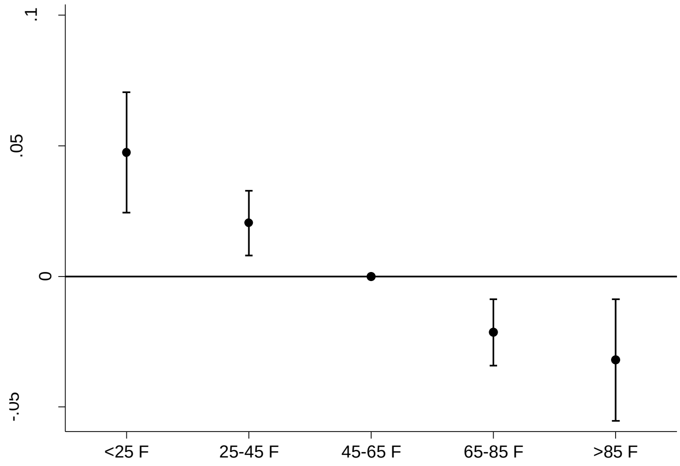
Figure 2: Distribution of daily mean temperature exposure during the gestation period



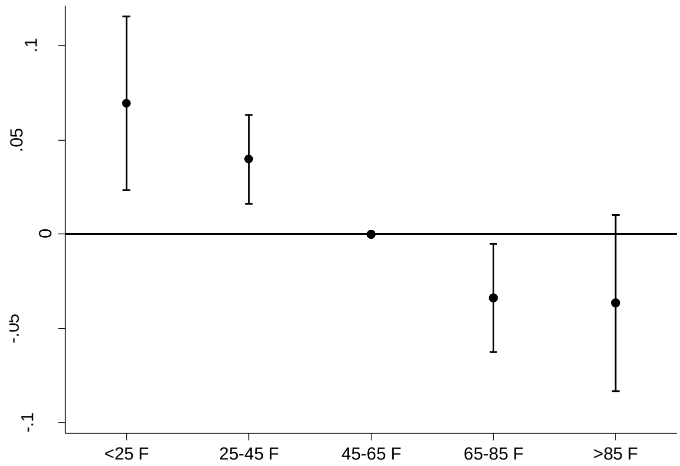
Source: China's National Disease Surveillance Points system; National Climatic Data Center, National Oceanic and Atmospheric Administration.

Figure 3: Estimated impacts of temperature on birth outcomes in the gestation period

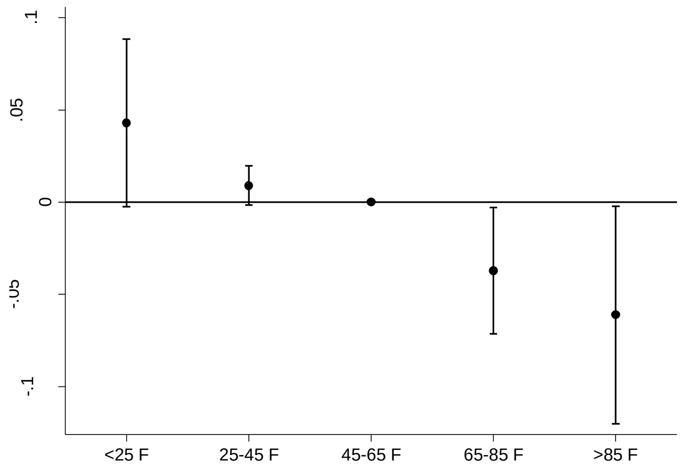
Panel A: Estimated impacts of temperature on low birth weight



Panel B: Estimated impacts of temperature on small for gestational age



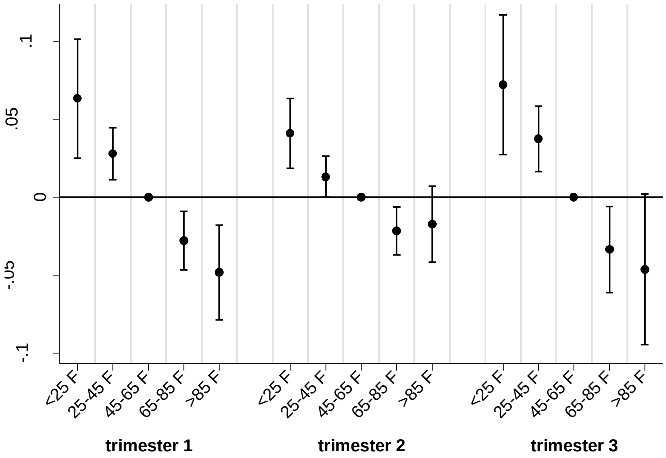
Panel C: Estimated impacts of temperature on birth defects



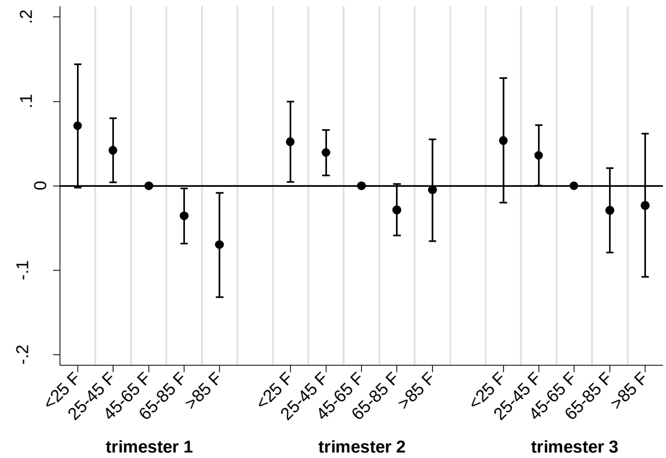
Note: The figure plots the estimated coefficients with 95% confidence intervals associated with each temperature bin identified from the regressions in Table A2. Panels A, B and C correspond to the three birth outcomes, low birth weight (i.e., <2,500 grams), small for gestational age and birth defects, respectively. The reference temperature bin is 45-65°F. **All the coefficients are scaled by 100 to make them more readable.** The coefficients can be interpreted as effects of an additional day in the temperature bin on birth outcomes relative to the reference temperature category.

Figure 4: Estimated impacts of temperature on birth outcomes in each trimester

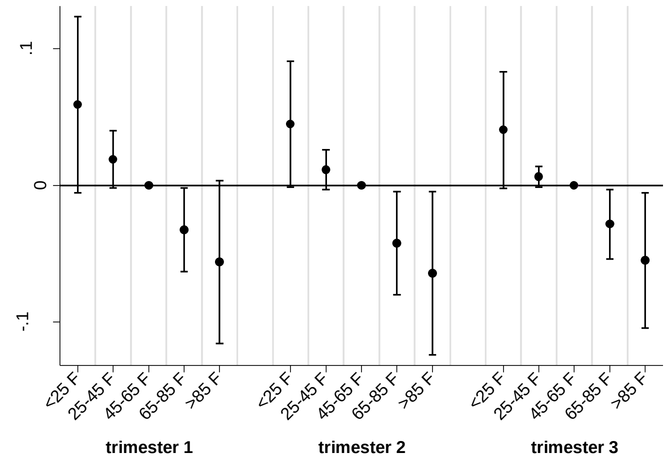
Panel A: Estimated impacts of temperature on low birth weight



Panel B: Estimated impacts of temperature on small for gestational age

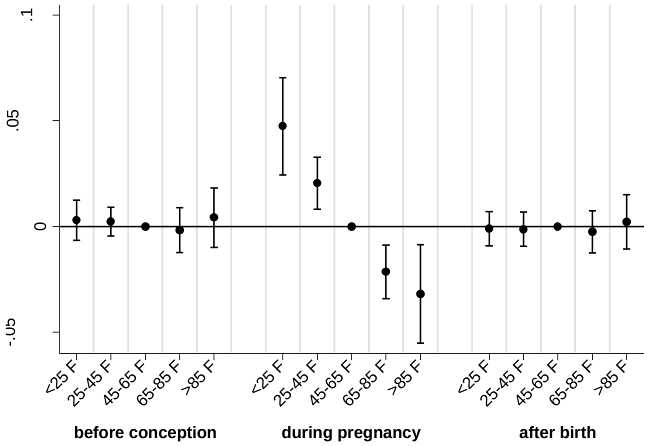


Panel C: Estimated impacts of temperature on birth defects

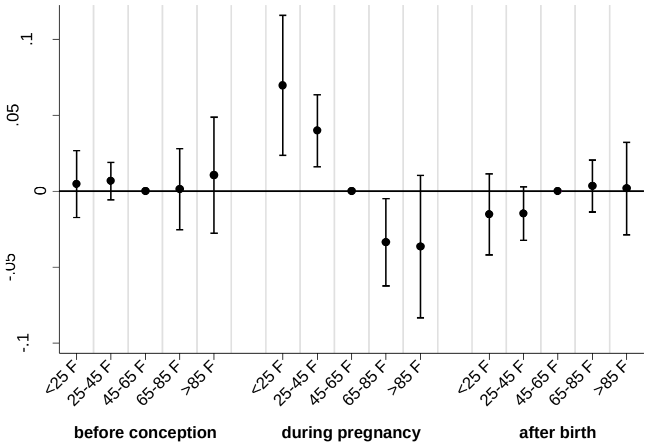


Note: The figure plots the estimated coefficients with 95% confidence intervals associated with each temperature bin in each trimester from the regressions in Table A3. Panels A, B and C correspond to the three birth outcomes, low birth weight (i.e., <2,500 grams), small for gestational age and birth defects, respectively. The reference temperature bin is 45-65°F. **All the coefficients are scaled by 100 to make them more readable.** The coefficients can be interpreted as effects of an additional day in the corresponding temperature bin and trimester on birth outcomes relative to the reference temperature category.

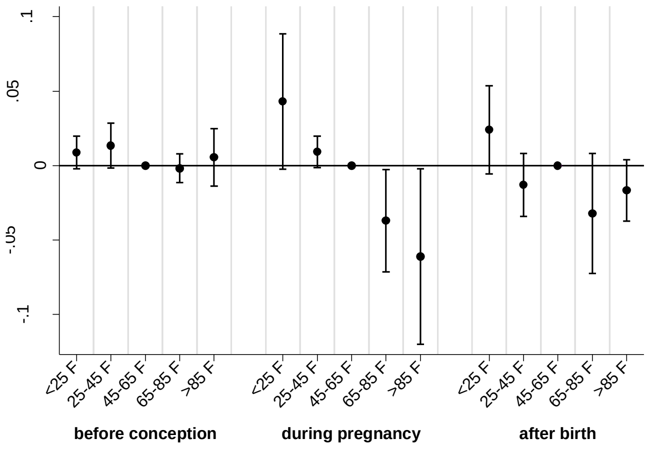
Figure 5: Placebo tests - Estimated impacts of temperature before conception and after birth
Panel A: Estimated impacts of temperature on low birth weight



Panel B: Estimated impacts of temperature on small for gestational age



Panel C: Estimated impacts of temperature on birth defects



Note: We match temperature exposure in three trimesters before conception and after birth with birth outcomes to conduct these placebo tests. Specifically, the left part of each panel plots the estimated coefficients with 95% confidence intervals associated with each temperature bin when matching temperature exposure in trimesters before conception. The right part is drawn based on the estimates after birth. The middle part replicates the baseline graphical results in Figure 3 for ease of comparison. Other covariates and fixed effects are the same as the baseline numerical results in Table A2. Panels A, B and C correspond to the three birth outcomes, respectively. The reference temperature bin is 45-65°F. **All the coefficients are scaled by 100 to make them more readable.**

Table 1: Mechanism tests - effects of temperature on parents' education, gender of child and number of birth

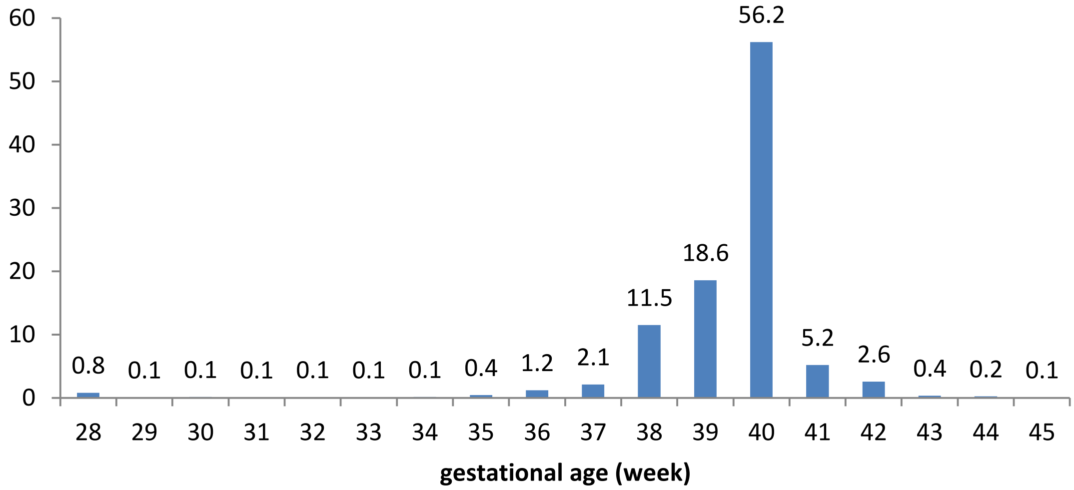
Dependent Variable	father's education above primary school	father's education above middle school	mother's education above primary school	mother's education above middle school	Child being female	number of birth at county-month level
	(1)	(2)	(3)	(4)	(5)	(6)
A. Mean temperature in conception month						
Mean temperature in the conception month	-0.001	-0.005	-0.003	-0.032*	0.046***	-0.108*
	(0.002)	(0.022)	(0.004)	(0.017)	(0.016)	(0.059)
Number of observations	253,486	253,486	339,972	339,972	340,285	5,152
Adjusted-R^2	0.035	0.222	0.075	0.272	0.008	0.703
B. The number of days in conception month						
the **number** of days in the conception month:						
<25 F	-0.001	0.033	0.001	0.063**	-0.048	0.153*
	(0.003)	(0.036)	(0.005)	(0.031)	(0.032)	(0.092)
25-45F	0.003	0.004	0.003	0.034	-0.054**	0.134
	(0.003)	(0.028)	(0.003)	(0.023)	(0.024)	(0.107)
45-65 F						
65-85 F	-0.001	-0.000	-0.004	-0.011	0.002	0.015
	(0.001)	(0.014)	(0.004)	(0.020)	(0.017)	(0.069)
>85 F	0.002	0.000	-0.009	-0.011	0.039	-0.484***
	(0.003)	(0.034)	(0.009)	(0.035)	(0.044)	(0.145)
Number of observations	253,486	253,486	339,972	339,972	340,285	5,152
Adjusted-R^2	0.036	0.222	0.075	0.272	0.008	0.704

Source: China's National Disease Surveillance Points system.

Note: *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively. Robust standard errors, clustered at the county level, are presented in parentheses. The dependent variables are dummies indicating the father's education above primary/middle school, the mother's education above primary/middle school, the gender of child, and the number of birth at county-month level. **All the coefficients in Columns (1) through (5) are scaled by 100 to make them more readable.** The left-out temperature bin is 45-65°F. All regressions include county fixed effects, province-by-year fixed effects, and birth month fixed effects. Results in Column (6) are generated from aggregate data at county-month level without birth month fixed effects included.

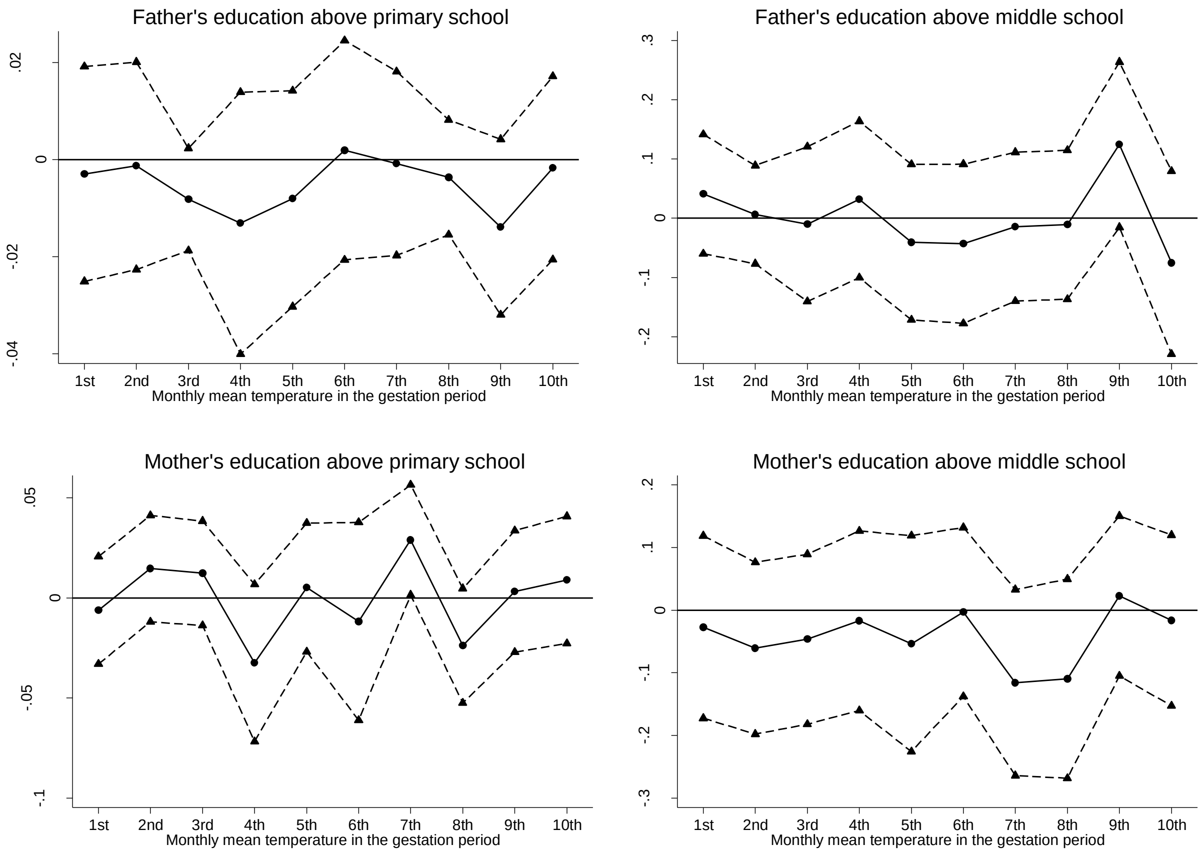
Online Appendix A: Supplementary Figures and Tables

Figure A1: Distribution of gestational age



Source: China's National Disease Surveillance Points system.

Figure A2: Mechanism tests - effects of monthly mean temperature in the gestation period on parents' education



Source: China's National Disease Surveillance Points system.
Note: The figure plots the coefficients with 95% confidence intervals from regressions of dummies indicating the father's education above primary/middle school and the mother's education above primary/middle school on ten monthly mean temperature in the gestation period. The regressions are estimated in the same way as those reported in Table 1. **All the coefficients are scaled by 100 to make them more readable.**

Table A1: Summary statistics

Variable	Mean	Std. Dev.
low birth weight	0.03	0.16
small for gestational age	0.09	0.29
birth defects	0.01	0.11
the **number** of days in:		
<25 F	11.19	24.66
25-45 F	53.76	37.05
45-65 F	84.36	28.17
65-85 F	115.04	50.52
>85 F	11.67	12.34
mean precipitation	0.11	0.08
mean visibility	8.84	2.95
mean dew point	48.79	12.36
mean wind speed	4.57	1.90
the number of fog days	29	40
male	0.55	0.50
birth order	1.32	0.56
mother age (÷ 10)	2.55	0.34
gestational age	39.43	1.63
mother education		
college or above	0.01	0.09
high school	0.25	0.44
middle school	0.59	0.49
primary school	0.14	0.35
illiterate	0.01	0.07

Source: China's National Disease Surveillance Points system.

Table A2: Effects of temperature exposure on birth outcomes in the gestation period

Dependent Variable	low birth weight	SGA	birth defects
	(1)	(2)	(3)
the **number** of days in:			
<25 F	0.047***	0.070***	0.043*
	(0.012)	(0.023)	(0.023)
25-45F	0.020***	0.040***	0.009*
	(0.006)	(0.012)	(0.005)
45-65 F			
65-85 F	-0.021***	-0.034**	-0.037**
	(0.006)	(0.014)	(0.017)
>85 F	-0.032***	-0.037	-0.061**
	(0.012)	(0.024)	(0.030)
mean precipitation	-1.236	-7.837***	0.262
	(1.055)	(2.629)	(0.621)
mean visibility	0.136	0.096	0.745
	(0.098)	(0.266)	(0.484)
mean dew point	0.225***	0.448***	0.187*
	(0.065)	(0.126)	(0.106)
mean wind speed	-0.098	-0.608	1.693*
	(0.139)	(0.416)	(0.915)
the number of fog days	0.002	0.004	-0.002
	(0.004)	(0.011)	(0.011)
male	-0.737***	-2.557***	0.021
	(0.114)	(0.321)	(0.017)
birth order	0.016	-0.525**	-0.065
	(0.073)	(0.220)	(0.067)
mother age (÷ 10)	-3.189**	-7.175**	-0.182
	(1.351)	(3.430)	(0.626)
mother age (÷ 10) square	0.519**	1.227**	0.036
	(0.237)	(0.566)	(0.101)
gestational age	-1.319***	-0.184	0.032
	(0.223)	(0.361)	(0.043)
Number of observations	312,568	312,568	331,886
Adjusted-R^2	0.094	0.085	0.796

Source: China's National Disease Surveillance Points system.

Note: This Table corresponds to the full estimation results of Figure 3. *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively. Robust standard errors, clustered at the county level, are presented in parentheses. The dependent variables are the indicators for low birth weight (i.e., <2,500 grams), small for gestational age and birth defects. **All the coefficients are scaled by 100 to make them more readable.** The left-out temperature bin is 45-65°F. All regressions include county fixed effects, province-by-year fixed effects, and birth month fixed effects. Demographic controls include dummies for mother's education, occupation and ethnicity. SGA = small for gestational age.

Table A3: Effects of temperature exposure on birth outcomes in each trimester

Dependent Variable	low birth weight (1)	SGA (2)	birth defects (3)
the **number** of days in trimester 1:			
<25 F - t1	0.063***	0.071*	0.059*
	(0.019)	(0.037)	(0.032)
25-45F - t1	0.028***	0.042**	0.019*
	(0.008)	(0.019)	(0.010)
45-65 F - t1			
65-85 F - t1	-0.028***	-0.036**	-0.032**
	(0.009)	(0.016)	(0.015)
>85 F - t1	-0.048***	-0.070**	-0.056*
	(0.015)	(0.031)	(0.030)
the **number** of days in trimester 2:			
<25 F - t2	0.041***	0.052**	0.045*
	(0.011)	(0.024)	(0.023)
25-45F - t2	0.013*	0.039***	0.012
	(0.007)	(0.013)	(0.007)
45-65 F - t2			
65-85 F - t2	-0.022***	-0.028*	-0.042**
	(0.008)	(0.015)	(0.019)
>85 F - t2	-0.017	-0.005	-0.064**
	(0.012)	(0.030)	(0.030)
the **number** of days in trimester 3:			
<25 F - t3	0.072***	0.054	0.041*
	(0.023)	(0.037)	(0.021)
25-45F - t3	0.037***	0.036**	0.006*
	(0.011)	(0.018)	(0.004)
45-65 F - t3			
65-85 F - t3	-0.034**	-0.029	-0.028**
	(0.014)	(0.025)	(0.013)
>85 F - t3	-0.046*	-0.023	-0.055**
	(0.024)	(0.043)	(0.025)
Number of observations	312,568	312,568	331,886
Adjusted-R^2	0.094	0.085	0.796

Source: China's National Disease Surveillance Points system.

Note: This Table corresponds to the full estimation results of Figure 4. *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively. Robust standard errors, clustered at the county level, are presented in parentheses. The dependent variables are the indicators for low birth weight (i.e., <2,500 grams), small for gestational age and birth defects. **All the coefficients are scaled by 100 to make them more readable.** The left-out temperature bin is 45-65°F. All regressions include county fixed effects, province-by-year fixed effects, and birth month fixed effects. Demographic controls include gender, birth order, mother's age and its square, gestational age, dummies for mother's education, occupation and ethnicity. Environmental controls include mean precipitation, visibility, dew points, wind speed and the number of fog days in each trimester. SGA = small for gestational age.

Table A4: Heterogeneous effects of temperature exposure on birth outcomes by gender

Dependent Variable	low birth weight		small for gestational age		birth defects	
	male	female	male	female	male	female
the **number** of days in:						
<25 F	0.037***	0.061***	0.047**	0.096***	0.038*	0.050**
	(0.012)	(0.014)	(0.022)	(0.028)	(0.023)	(0.023)
25-45 F	0.020**	0.021***	0.034***	0.046***	0.009	0.010*
	(0.008)	(0.007)	(0.012)	(0.014)	(0.005)	(0.005)
45-65 F						
65-85 F	-0.016***	-0.029***	-0.020	-0.052***	-0.036**	-0.039**
	(0.005)	(0.009)	(0.013)	(0.019)	(0.017)	(0.017)
>85 F	-0.028***	-0.038**	-0.014	-0.063**	-0.058*	-0.066**
	(0.010)	(0.015)	(0.020)	(0.032)	(0.029)	(0.030)
Number of observations	172,295	140,273	172,295	140,273	183,212	148,674
Adjusted-R^2	0.103	0.087	0.081	0.089	0.787	0.807

Source: China's National Disease Surveillance Points system.

Note: *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively. Robust standard errors, clustered at the county level, are presented in parentheses. The dependent variables are indicators for low birth weight (i.e., <2,500 grams), small for gestational age and birth defects. **All the coefficients are scaled by 100 to make them more readable.** The left-out temperature bin is 45-65°F. All regressions include county fixed effects, province-by-year fixed effects, and birth month fixed effects. Demographic controls include gender, birth order, mother's age and its square, gestational age, dummies for mother's education, occupation and ethnicity. Environmental controls include mean precipitation, visibility, dew points, wind speed and the number of fog days.

Table A5: Effects of temperature exposure on birth outcomes in the gestation period, by north & south

Dependent Variable	low birth weight			small for gestational age			birth defects		
	all	north	south	all	north	south	all	north	south
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
the **number** of days in:									
<25 F	0.058***	0.024**	0.076***	0.081**	0.055*	0.097**	0.051**	0.060**	0.004
	(0.018)	(0.012)	(0.021)	(0.032)	(0.032)	(0.037)	(0.023)	(0.028)	(0.003)
<25 F×north	-0.007			-0.009			-0.013		
	(0.009)			(0.016)			(0.010)		
25-45 F	0.015**	0.017**	0.026***	0.035**	0.041*	0.036**	0.009*	0.029*	-0.000
	(0.007)	(0.008)	(0.009)	(0.013)	(0.023)	(0.014)	(0.005)	(0.015)	(0.001)
25-45 F×north	0.017			0.012			-0.005		
	(0.012)			(0.028)			(0.007)		
45-65 F									
45-65 F×north									
65-85 F	-0.027***	0.001	-0.035***	-0.038*	-0.000	-0.049**	-0.035**	-0.048**	-0.002
	(0.009)	(0.007)	(0.010)	(0.020)	(0.016)	(0.022)	(0.016)	(0.022)	(0.002)
65-85 F×north	0.013			0.014			-0.008		
	(0.010)			(0.025)			(0.008)		
>85 F	-0.035**	-0.014	-0.048***	-0.029	-0.031	-0.043	-0.062**	-0.110**	-0.002
	(0.014)	(0.013)	(0.017)	(0.028)	(0.031)	(0.032)	(0.031)	(0.047)	(0.003)
>85 F×north	0.005			-0.031			0.002		
	(0.015)			(0.019)			(0.015)		
Number of observations	312,568	112,691	199,877	312,568	112,691	199,877	331,886	127,090	204,796
Adjusted-R^2	0.094	0.024	0.115	0.085	0.062	0.091	0.796	0.840	0.003

Source: China's National Disease Surveillance Points system.

Note: *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively. Robust standard errors, clustered at the county level, are presented in parentheses. The dependent variables are indicators for low birth weight (i.e., <2,500 grams), small for gestational age and birth defects. **All the coefficients are scaled by 100 to make them more readable.** The left-out temperature bin is 45-65°F. All regressions include north dummy, county fixed effects, province-by-year fixed effects, and birth month fixed effects. Demographic controls include gender, birth order, mother's age and its square, gestational age, dummies for mother's education, occupation and ethnicity. Environmental controls include mean precipitation, visibility, dew points, wind speed and the number of fog days.