

Climate Change and Birth Weight

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Climate Change and Birth Weight

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There is a growing consensus that emissions of greenhouse gases due to human activity will alter the earth's climate, most notably by causing temperatures, precipitation levels, and weather variability to increase. The design of optimal climate change mitigation policies requires estimates of the health and other benefits of reductions in greenhouse gases; current evidence on the magnitudes of the direct and indirect impacts, however, is considered insufficient for reliable conclusions (A.J. McMichael et al, 2003).¹

In addition to the overall predicted warming trend, one important feature of many global climate change forecasts is an increased incidence of very high and low temperatures. To provide evidence of the potential benefits of greenhouse gas reductions, this paper documents whether the temperature variation predicted to be part of climate change, including extreme high and low temperatures, historically have had negative health consequences through their effect on babies while *in utero*.

Using individual-level data on more than 37.1 million births, we find that exposure to extreme hot temperatures during pregnancy leads to lower birth weights. We combine this finding with estimates of the distribution of future daily temperatures from state of the art climate change predictions. We then use these predictions of the effect of climate change on the

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¹ See Richard S.J. Tol (2002a, b) for overall estimates of the costs of climate change, which are obtained by summing costs over multiple areas including human health, agriculture, forestry, species/ecosystems, and sea level rise. Olivier Deschenes and Michael Greenstone (2007) provides evidence on the impacts on the U.S. agriculture sector. Deschenes and Greenstone (2008) and Robin Burgess et al (2009) estimate the mortality impacts of climate change in the U.S. and India, respectively.

distribution of daily temperatures to estimate the predicted effect of global climate change on future birth weights by the end of the century. These estimates imply that mean birth weights will decrease on average by 0.22 percent (7.5 grams) among whites and by 0.36 percent (11.5 grams) for blacks by the end of the century. Further, the impact is not spread evenly through the birth weight distribution. We find an estimated 5.9% increase in the probability of a low birth weight birth (defined as less than 2,500 grams) for whites and a 5.0% increase for blacks.²

A small set of studies attempt to explain seasonality in birth weight with exposure to extreme temperatures *in utero* (L. J. Murray et al, 2000; D.A. Lawlor, D.A. Leon, and G.D. Smith, 2005). Although there is some evidence of a negative relationship between mean temperatures and birth weight, the absence of a cohesive framework, limited statistical models, and relatively small samples have limited the development of clear stylized facts. Further, no consensus has emerged concerning the physiological mechanisms linking heat and cold stress *in utero*, although fetal nutrient intake is often mentioned without direct evidence.

Our detailed historical temperature data allow us to date specifically each shock to the conditions experienced *in utero*. We are thus able to estimate not only the effects of exposure to extreme temperature while *in utero*, but to explore how this effect varies according to the timing during gestation. This allows us to shed light on the mechanisms at work in fetal programming. Of particular interest, we find that as much as 95 percent of the effect of *in utero* exposure to very hot ambient temperatures occurs for exposure during the second and third trimesters.

I. Data Sources and Summary Statistics

² This study of the impact of extreme temperature exposure on birth weight is related to the fetal origins hypothesis (David J. P. Barker, 1994). In its extended form, it states that economic and environmental conditions during pregnancy may have long-lasting impacts on long-term health and socioeconomic status (see e.g., Douglas Almond, 2006; Sandra Black et al, 2007; Heather Royer 2009). A key variable in this literature is birth weight, which is considered by some to be a summary measure of the fetal experience. Future work will investigate whether exposure to extreme temperatures affects long-run economic and health outcomes, whether through its effect on birth weight or on latent factors that do not affect birth weight directly.

To implement the analysis, we collected the most detailed and comprehensive data available on infant birth outcomes, weather, and predicted climate change. This section describes these data and reports summary statistics. See Olivier Deschenes and Michael Greenstone (2008) for further details.

A. Data Sources

Birth Weight Data. Microdata on birth weight and exact date of birth are taken from the 1972-1988 National Center for Health Statistics Natality Detail Files (NDF). The data include exact date of birth, race, sex, birth weight, county of birth, mother's marital status, mother's education, and the exact date of the mother's last menstrual period. From the latter we infer the date of 'conception' and measure the trimesters of the pregnancy relative to that date. This is preferable to dating gestation age relative to the date of birth, since gestation length itself may be an outcome of exposure to extreme temperatures. Observations are dropped from the analysis sample if either race, sex, birth weight or date of last menstrual period is missing. The sample includes 37.1 million singleton births to mothers aged 16-45 in the continental 48 states and D.C.

Weather Data. The weather data are drawn from the National Climatic Data Center Summary of the Day Data (File TD-3200). The key variables for our analysis are the daily maximum and minimum temperature, which we average to construct daily average temperature. Station-level weather data are aggregated at the county level by taking an inverse-distance weighted average of all the valid measurements from stations that are located within a 200 km radius of each county's centroid.

Climate Change Prediction Data. Climate predictions are taken from the application of the A2 scenario to the National Center for Atmospheric Research's Community Climate System Model (CCSM) 3, which is a state of the art coupled atmospheric-ocean general circulation

model (National Center for Atmospheric Research, 2007). We use the CCSM 3 A2 daily temperature predictions for grid points throughout the continental U.S. for the years 2070-2099. From the CCSM predictions, we assign each county a daily weather realization, aggregating in the same way we aggregate the contemporaneous temperatures. Each county's end of century predicted climate is the simple average of the predicted weather realizations for the 2070-2099 period.

B. Descriptive Statistics

Birth Outcomes Statistics. The main analysis will examine the effect of extreme temperatures on birth weights, by race. There are substantial differences in birth outcomes between blacks and whites. Mean birth weights are higher for whites (3,417 grams), by about 235 grams. The percent of 'low birth weight' births is more than twice as large for blacks than whites (9.3% compared to 4.1%), while the black gestational period is 5 days shorter on average. For both races there are marked seasonal differences in birth outcomes, including birth weight and the number of births, across quarters of conception.

If differences in fertility by date of conception reflect differences in socioeconomic, health, or overall fertility attributes, associations between temperature exposure and pregnancy outcomes may be confounded. We address the potential confounding of socioeconomic and health attributes with the timing of conception by utilizing county-level inter-annual variation in temperature and controlling for a smooth function of the date of conception.

Weather and Climate Change Statistics. The regressors of interest in the analysis are the number of days during the gestation period in which a county's daily average (mean of the minimum and maximum) temperature falls into each of five temperature bins ($< 25^\circ$ F, $25^\circ - 45^\circ$ F, $45^\circ - 65^\circ$ F, $65^\circ - 85^\circ$ F, $> 85^\circ$ F). In Figure 1, the white bars depict the average distribution

of daily mean temperature exposure over the course of the typical pregnancy in the U.S. between 1972 and 1988. In the 270 days after conception, the average pregnancy in the U.S. is exposed to 13.4 days with a temperature less than 25° F, 252.8 days in the 25° - 85° F range, and 3.8 days greater than 85° F. In the subsequent analysis, these bins are calculated separately by trimester of the pregnancy so to allow for substantial flexibility in the semi-parametric modeling of the effect of temperature on birth weight. The average pregnancy is exposed to 13.4 days lower than 25° F and 3.8 days warmer than 85° F.

After we estimate the effect of temperature exposure *in utero* on birth weight, we will estimate the implied effect on birth weight of the 2070-2099 CCSM 3 A2 temperature predictions.³ The black bars in Figure 1 reports on the predicted change in the number of days in each of the temperature bins, assuming the geographic distribution of births remains constant. The CCSM 3 A2 predictions are that the typical pregnancy will be exposed to 7.8 fewer days below 25° F per year and 29.9 more days in excess of 85° F. The majority of this temperature increase comes from a reduction of 24.1 days in the 45° - 65° F bin.⁴

II. Econometric Strategy

The subsequent results are based on the fitting of the following equation:

$$(1) \quad Y_i = \sum_j \theta_g^{TR1} TMEAN_{ctdj}^{TR1} + \sum_j \theta_g^{TR2} TMEAN_{ctdj}^{TR2} + \sum_j \theta_g^{TR3} TMEAN_{ctdj}^{TR3} + X_i \beta + \alpha_{ctg} + f(d_g) + \varepsilon_i$$

where the *i* denotes the individual birth, *c* the county, *t* the year, *g* the demographic group (defined by sex and race), and *d* represents the ‘day of the year’ of conception, which ranges from 1-365. Therefore, the indices *t* and *d* fully determine the exact date of conception.

³ For comparability, we follow much of the previous literature on climate change and focus on the temperatures predicted to prevail at the end of the century. We were unable to obtain CCSM 3 A2 predictions for the past, so the magnitude of any model errors is unknown and we cannot adjust the predicted temperature changes for such errors.

⁴ We focus on averages although there is substantial heterogeneity in historical temperatures and climate change predictions.

The two dependent variables are log birth weight and an indicator for low birth weight (i.e., less than 2,500 grams). Individual level controls for mother’s age, fertility history, marital status, and educational attainment are included in the vector X_i . The county-year-demographic group fixed effects, α_{ctg} , account for cross-sectional variation in temperature and birth weight and a quartic in conception date ranges (ranging from 1-365), $f(d_g)$, accounts for demographic group-specific seasonality. These variables are included to capture the effect of any secular difference in birth outcomes within year that is independent of temperature exposure. The last term in the equation is the stochastic error term, ε_i . We report standard errors that are clustered at the county-by-demographic group level. We also weight by the ‘record weight’ variable contained in the NDF.

The variables of interest, $TMEAN_{ctdj}^{TR1}$, $TMEAN_{ctdj}^{TR2}$, and $TMEAN_{ctdj}^{TR3}$, are the measures of temperature exposure during each trimester of the gestational period. The j index refers to the five daily mean temperature bins described above. The choice of five temperature bins is motivated by an effort to allow the data, rather than parametric assumptions, to determine the birth weight-temperature exposure relationship, while also obtaining estimates that have empirical content.⁵ By conditioning on county-year-demographic group effects, the associated parameters are identified from county-specific deviations in weather about the county averages, after controlling for county-specific annual shocks. Due to the unpredictability of temperature fluctuations, we presume that this variation is orthogonal to unobserved determinants of birth weight.

III. Results

Figure 2 plots the estimated regression coefficients associated with each temperature bin,

⁵ A similar methodology is used in Deschenes and Greenstone (2007).

by trimester, from a model that pools all births and includes gender-by-race indicators. The panels A, B, and C correspond to the three trimesters. In each case the reference bin is 45°-65° F, so each coefficient measures the impact of an additional day in a given bin in a given trimester on the log birth weight, relative to the impact of a day between 45° and 65° F. The figure also plots the 95% confidence interval associated with the estimates.

The figures show a strong negative relationship between birth weight and temperature. In each of the three trimesters, the response function is downward-sloping, with the relationship more pronounced for the second and third trimesters. For all three trimesters, exposure to hot days is associated with a statistically significant decline in birth weight, which ranges in magnitude from 0.003% to 0.009% per such day, relative to a day in the reference category. The third trimester effect is likely an underestimate because many of the births are delivered less than 270 days after conception.

Table 1 presents calculations of the predicted impacts of climate change on birth weight outcomes, based on CCSM 3 A2 end of century predictions. Panel A pertains to whites and panel B to blacks. To calculate the implied impact of climate change on birth weight for each county on each conception date, we multiply the estimated θ 's for each trimester by the predicted change in days in each temperature bin for each trimester. We then report the weighted average across counties and over the calendar year. It is straightforward to calculate the standard error of this prediction (reported below the estimate in parentheses), since the estimated mortality change is a linear function of the parameters.

Columns (1) – (3) report this calculation for gestational trimesters 1-3 while column (4) sums the impact across trimesters to obtain the full effect on log birth weights. For each panel we report three temperature categories (i.e., < 25° F, 25° - 85° F, and > 85° F) along with the

‘total impact’, which sums across the whole daily temperature distribution. Taken as a whole, the CCSM 3 A2 results suggest that climate change would lead to a reduction in average birth weights of 0.22 percent (whites) to 0.36 percent (blacks). In terms of actual weights, these reductions correspond to losses of 7.5 and 11.5 grams respectively. The null hypothesis of a zero effect is easily rejected at conventional significance levels.

Colum (5) repeats this exercise, except the dependent variable is now an indicator for whether the birth is designated as low birth weight. The estimated impacts for this outcome are substantially larger. In particular, climate change is predicted to increase the fraction of low birth weight births by roughly 5.9 percent for whites and 5.0 percent for blacks. It is evident that the impacts of temperature on weight are not equal through the birth weight distribution.

Two further findings are noteworthy. First, the birth weight reduction predicted by climate change models is almost entirely attributable to the predicted increase in exposure to ‘hot’ temperatures. Across both races and outcome variables, 79%- 94% of the estimated change is due to the increased number of days exceeding 85° F. Second, the impacts are concentrated in the second and third trimesters. For example, between 91% and 97% of the full gestational impact of climate change on birth weights comes from the second and third trimesters.

IV. Conclusions and Future Directions

In addition to a predicted increase in average temperature, many global climate change models contain the oft-overlooked prediction that there will be a large increase in the number of very hot days. Using inter-annual variation from long-run county-level temperature distributions, our estimates imply that exposure to such extreme ambient temperatures have deleterious effects on fetal health, causing a decrease in birth weight and an increase in the probability of low birth weight. The sensitivity of birth weight to temperature is concentrated

almost completely in the second and third trimesters of the pregnancy, though it is not yet clear whether this is due to a compensatory mechanism that operates during the first trimester or because negative shocks to fetal health in the first trimester show up in indicators other than birth weight. Our analysis also does not identify the effect of temperature exposure that works through nutrient accumulation separately from the direct effect on gestation length.

There are a few important caveats to these calculations and, more generally, to the analysis. The estimated impacts likely overstate the impacts, because the analysis relies on inter-annual variation in weather, and a greater array of adaptations (e.g., migration) will be available in response to permanent climate change. Additionally, an effort to project outcomes at the end of the century requires a number of strong assumptions, including that the climate change predictions are correct, relative prices will remain constant, the same medical technologies will prevail, and the demographic characteristics of parents and their geographical distribution will remain unchanged. The benefit of these strong assumptions is that they allow for a transparent analysis that isolates the impact of temperature on birth weight and is based on data rather than on unverifiable assumptions.

The important question left unanswered by this paper is whether these changes in birth weight are related to welfare losses; for example, through changes in health, human capital, income, or neonatal mortality. If there is indeed a relationship between *in utero* exposure to high temperature and welfare measures, then these impacts should become part of the calculations of the benefits of greenhouse gas reductions. This is an important topic for future research.

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Table 1: Estimated Impact of Climate Change on Birth Weights, Based on CCSM 3 A2 Predictions

| | Impact of change in temperature exposure during: | | | Full Gestational Period (4) | Full Gestational Period (birth weight <= 2500 gr) (5) |
|-----------------------------|--|----------------------|----------------------|--------------------------------|---|
| | 1st Trimester (1) | 2nd Trimester (2) | 3rd Trimester (3) | | |
| [A] Whites | | | | | |
| Total impact (percent) | -0.0002 (0.0002) | -0.0010 (0.0001) | -0.0010 (0.0001) | -0.0022 (0.0004) | 0.0585 (0.0098) |
| 1. Days Less Than 25F | 0.0001 (0.0000) | -0.0001 (0.0000) | -0.0001 (0.0000) | 0.0000 (0.0001) | 0.0049 (0.0024) |
| 2. Days Between 25F and 85F | 0.0000 (0.0000) | -0.0002 (0.0000) | -0.0001 (0.0000) | -0.0003 (0.0000) | 0.0073 (0.0000) |
| 3. Days More Than 85F | 0.0003 (0.0001) | -0.0007 (0.0001) | -0.0009 (0.0002) | -0.0019 (0.0003) | 0.0463 (0.0073) |
| [B] Blacks | | | | | |
| Total impact (percent) | -0.0001 (0.0006) | -0.0018 (0.0004) | -0.0017 (0.0004) | -0.0036 (0.0010) | 0.0495 (0.0129) |
| 1. Days Less Than 25F | 0.0000 (0.0000) | -0.0001 (0.0000) | -0.0001 (0.0000) | -0.0002 (0.0001) | 0.0032 (0.0022) |
| 2. Days Between 25F and 85F | 0.0000 (0.0001) | -0.0001 (0.0000) | 0.0000 (0.0000) | -0.0001 (0.0000) | 0.0022 (0.0011) |
| 3. Days More Than 85F | -0.0002 (0.0005) | -0.0016 (0.0004) | -0.0016 (0.0004) | -0.0034 (0.0009) | 0.0441 (0.0118) |

Notes: The estimates are from fixed effect regressions models estimated separately by race. Each model includes county-by-year fixed effects, a quartic polynomial in date of conception, an indicator for the baby’s sex, and controls for mother characteristics. The dependent variables are the log birth weight and an indicator for low birth weight status (i.e., < 2,500 grams). Standard errors are clustered at the county-by-race level. See the text for further details

Figure 1: Distribution of Historical and Predicted Exposure Days in 5 Daily Temperature Bins

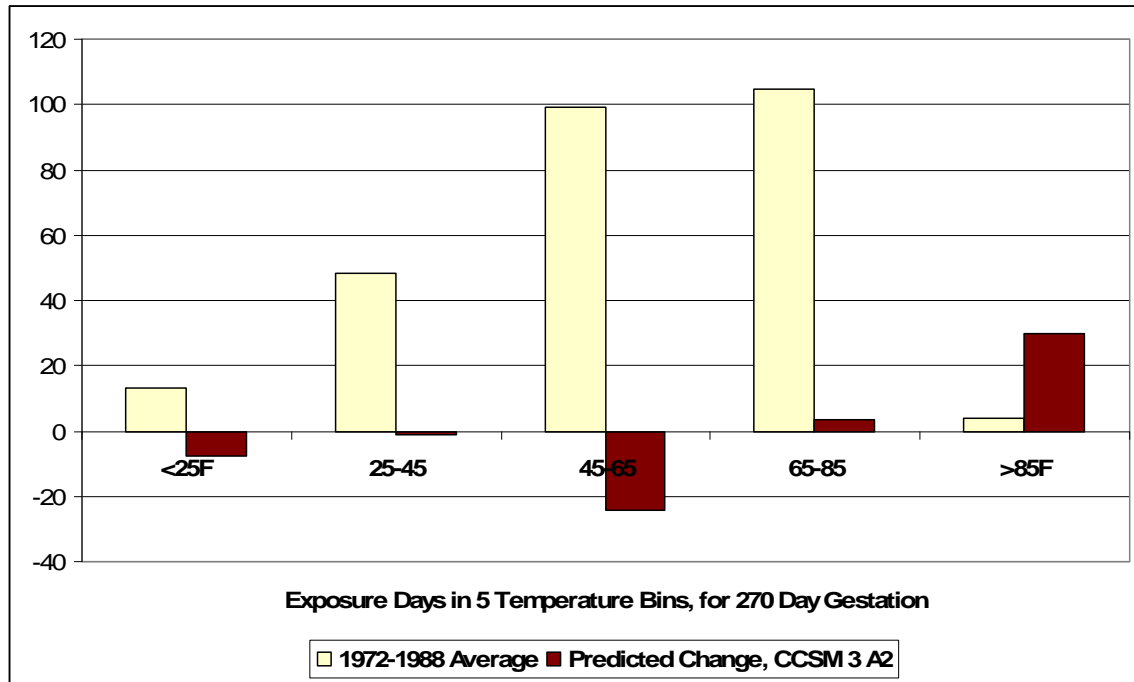
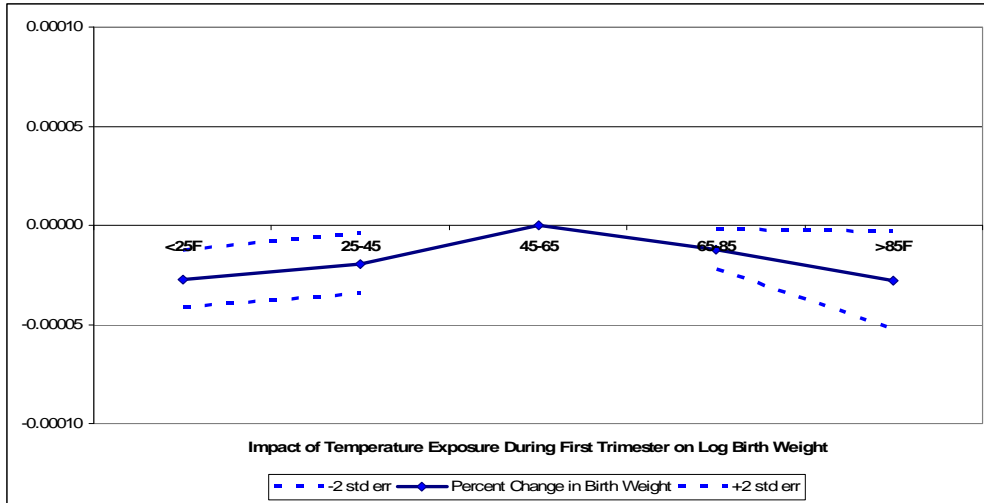
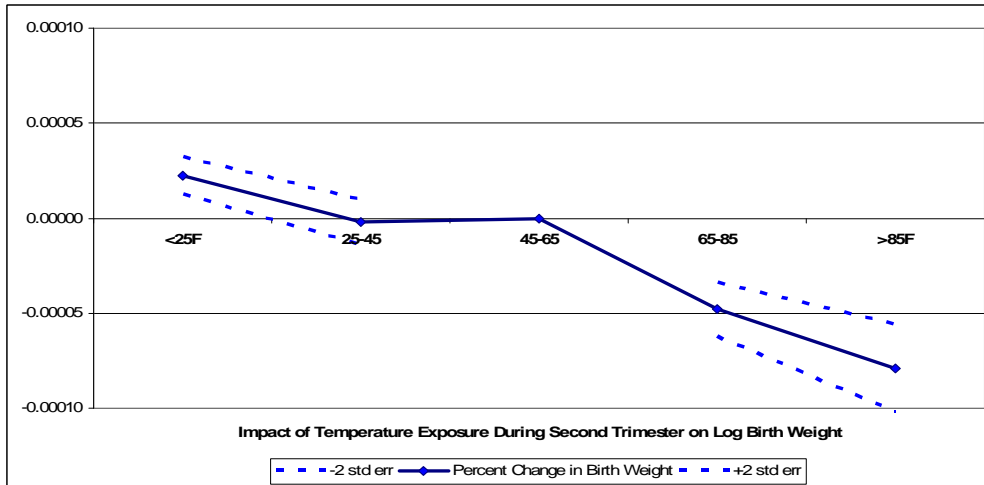


Figure 2: Impact of Temperature Exposure During Gestational Period on Birth Weight
(A) First Trimester



(B) Second Trimester



(C) Third Trimester

