

## 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 magnitude of the direct and indirect impacts, however, is considered insufficient for reliable conclusions (A. J. McMichael et al. 2003).<sup>1</sup>

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 has had negative health consequences through its 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 weight. 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 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 percent increase in the probability of a low birth weight birth (defined as less than 2,500 grams) for whites and a 5.0 percent increase for blacks.<sup>2</sup>

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; Debbie A. Lawlor, David A. Leon, and George Davey 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.

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<sup>1</sup> 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. Deschênes and Greenstone (2007b) provide evidence on the impacts on the US agriculture sector. Deschênes and Greenstone (2007a) and Robin Burgess et al. (2009) estimate the mortality impacts of climate change in the United States and India, respectively.

<sup>2</sup> 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, Paul J. Devereux, and Kjell G. Salvanes 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.

Our detailed historical temperature data allow us to date specifically each shock to the conditions experienced in utero. We are thus able not only to estimate the effects of exposure to extreme temperature while in utero, but also 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 from exposure during the second and third trimesters.

### I. Data Sources and Summary Statistics

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 Deschênes and Greenstone (2007a) for further details.

#### A. Data Sources

*Birth Weight Data.*—Microdata on birth weight and 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 last factor 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 age 16–45 in the continental 48 states and the District of Columbia.

*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 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 United States 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 Outcome Statistics.*—The main analysis will examine the effect of extreme temperatures on birth weight, 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 percent compared to 4.1 percent), while the black gestational period is five 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 interannual 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

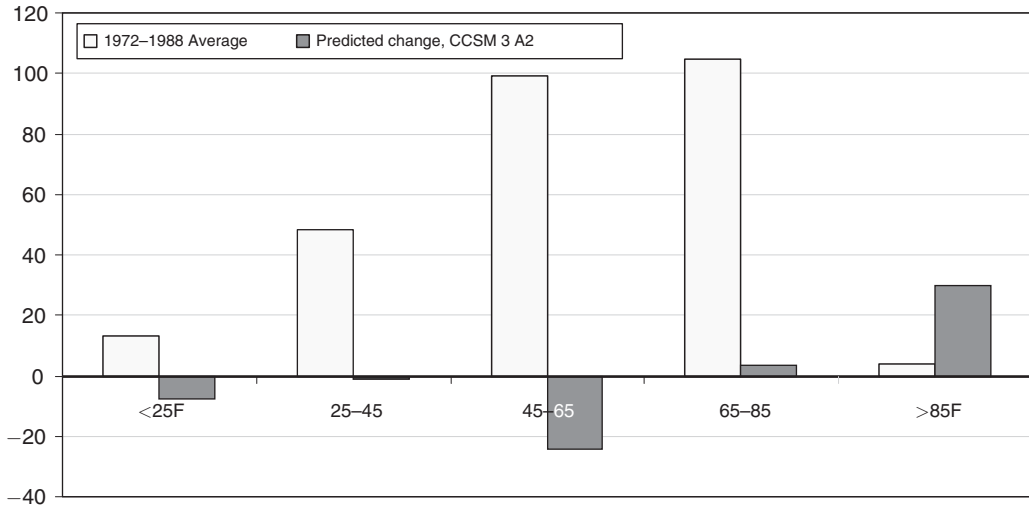


FIGURE 1. DISTRIBUTION OF HISTORICAL AND PREDICTED EXPOSURE DAYS IN FIVE DAILY TEMPERATURE BINS (For 270-day gestation)

each of five temperature bins (< 25°F, 25°–45°F, 45°–65°F, 65°–85°F, > 85°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 US between 1972 and 1988. In the 270 days after conception, the average pregnancy in the US 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 to allow for substantial flexibility in the semiparametric 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.<sup>3</sup> The black bars in Figure 1 report 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.<sup>4</sup>

## II. Econometric Strategy

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

$$\begin{aligned}
 (1) \quad Y_i = & \sum_j \theta_{gj}^{TR1} TMEAN_{ctdj}^{TR1} \\
 & + \sum_j \theta_{gj}^{TR2} TMEAN_{ctdj}^{TR2} \\
 & + \sum_j \theta_{gj}^{TR3} TMEAN_{ctdj}^{TR3} \\
 & + \mathbf{X}_i\beta + \alpha_{ctg} + f(d_g) + \varepsilon_i,
 \end{aligned}$$

where  $i$  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

<sup>3</sup> 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.

<sup>4</sup> We focus on averages, although there is substantial geographic heterogeneity in historical temperatures and climate change predictions.

from 1–365. Therefore, the indices  $t$  and  $d$  fully determine the exact date of conception.

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  $\mathbf{X}_i$ . The county-year-demographic group fixed effects,  $\alpha_{ctg}$ , account for cross-sectional variation in temperature and birth weight and a quartic in conception date ranges (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,  $\varepsilon_i$ . 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.<sup>5</sup> 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, 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 addi-

tional 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 percent confidence interval associated with the estimates.

The figures show a strong negative relationship between birth weight and temperature, particularly in 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 percent to 0.009 percent 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 fewer 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  $\theta$ '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 (< 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) and 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.

Column 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

<sup>5</sup> A similar methodology is used in Deschênes and Greenstone (2007b).

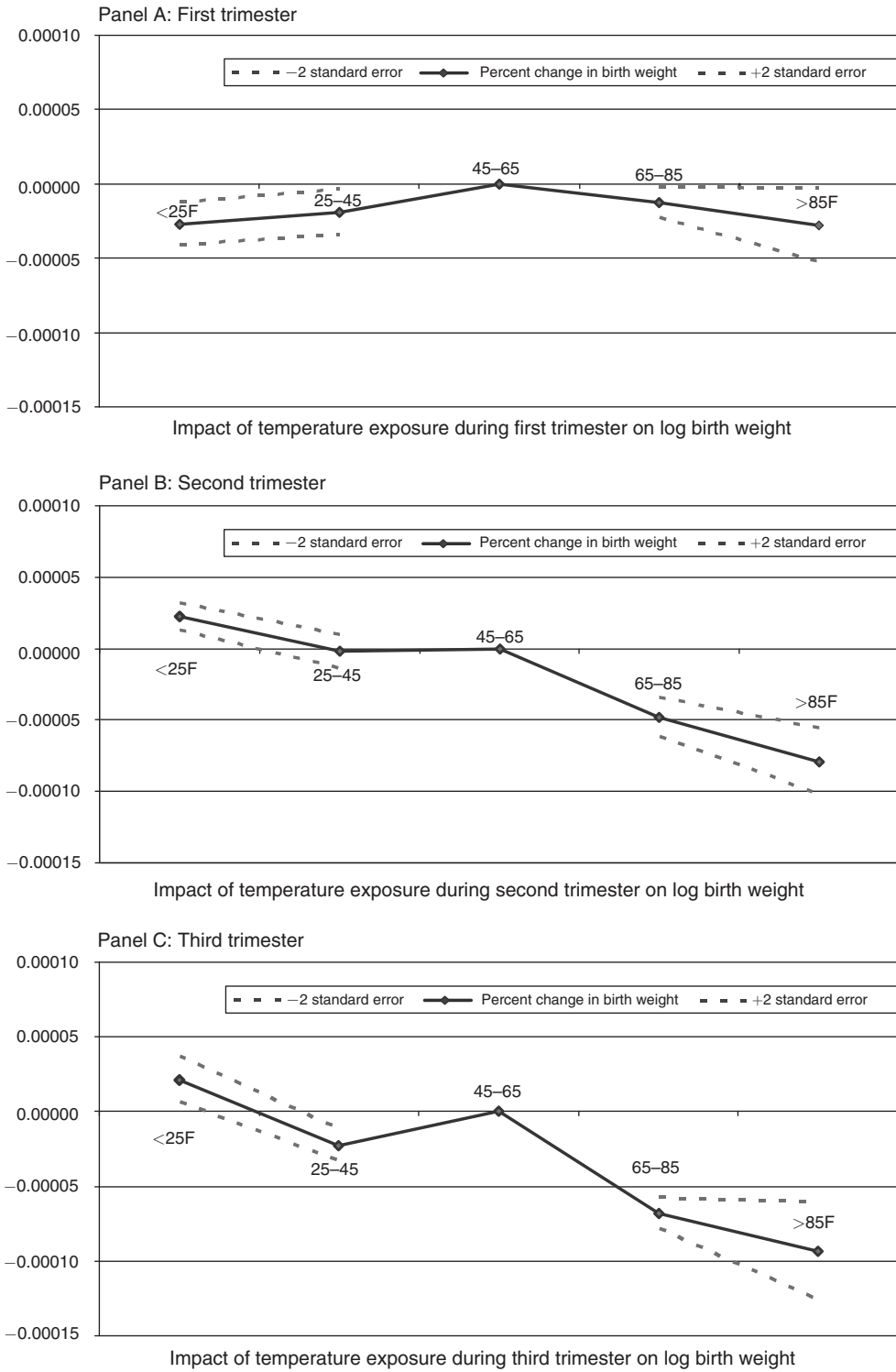


FIGURE 2. IMPACT OF TEMPERATURE EXPOSURE DURING GESTATIONAL PERIOD ON BIRTH WEIGHT

TABLE 1—ESTIMATED IMPACT OF CLIMATE CHANGE ON BIRTH WEIGHT, BASED ON CCSM 3 A2 PREDICTIONS

	Impact of change in temperature exposure during:			Full gestational period (4)	Full gestational period (birth weight ≤ 2,500 gr) (5)
	1st trimester (1)	2nd trimester (2)	3rd trimester (3)		
<i>Panel A: Whites</i>					
Total impact (percent)	−0.0002 (0.0002)	−0.0010 (0.0001)	−0.0010 (0.0001)	−0.0022 (0.0004)	0.0585 (0.0098)
Days less than 25°F	0.0001 (0.0000)	−0.0001 (0.0000)	−0.0001 (0.0000)	0.0000 (0.0001)	0.0049 (0.0024)
Days between 25°F and 85°F	0.0000 (0.0000)	−0.0002 (0.0000)	−0.0001 (0.0000)	−0.0003 (0.0000)	0.0073 (0.0000)
Days more than 85°F	0.0003 (0.0001)	−0.0007 (0.0001)	−0.0009 (0.0002)	−0.0019 (0.0003)	0.0463 (0.0073)
<i>Panel B: Blacks</i>					
Total impact (percent)	−0.0001 (0.0006)	−0.0018 (0.0004)	−0.0017 (0.0004)	−0.0036 (0.0010)	0.0495 (0.0129)
Days less than 25°F	0.0000 (0.0000)	−0.0001 (0.0000)	−0.0001 (0.0000)	−0.0002 (0.0001)	0.0032 (0.0022)
Days between 25°F and 85°F	0.0000 (0.0001)	−0.0001 (0.0000)	0.0000 (0.0000)	−0.0001 (0.0000)	0.0022 (0.0011)
Days more than 85°F	−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 regression 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.

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 percent 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 percent and 97 percent of the full gestational impact of climate change on birth weight 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 interannual variation from long-

run county-level temperature distributions, our estimates imply that exposure to such extreme ambient temperatures has 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 interannual 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.

#### REFERENCES

- ▶ **Almond, Douglas.** 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.
- Barker, David J. P.** 1994. *Mothers, Babies, and Disease in Later Life*. London: BMJ Publishing Group.
- ▶ **Black, Sandra E., Paul J. Devereux, and Kjell G. Salvanes.** 2007. "From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes." *Quarterly Journal of Economics*, 122(1): 409–39.
- Burgess, Robin, Olivier Deschênes, Dave Donaldson, and Michael Greenstone.** 2009. "Climate Change, Consumption Smoothing, and Mortality in India." Unpublished.
- Deschênes, Olivier, and Michael Greenstone.** 2007a. "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US." MIT Working Paper revised 2008. 07–19.
- ▶ **Deschênes, Olivier, and Michael Greenstone.** 2007b. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *American Economic Review*, 97(1): 354–85.
- ▶ **Lawlor, Debbie A., David A. Leon, and George Davey Smith.** 2005. "The Association of Ambient Outdoor Temperature throughout Pregnancy and Offspring Birthweight: Findings from the Aberdeen Children of the 1950s Cohort." *BJOG: An International Journal of Obstetrics & Gynaecology*, 112(5): 647–57.
- McMichael, A. J., D. H. Campbell-Lendrum, C. F. Corvalan, K. L. Ebi, A. Githelo, J. D. Scheraga, and A. Woodward, ed.** 2003. *Climate Change and Human Health: Risks and Responses*. Geneva: World Health Organization.
- ▶ **Murray, L. J., D. P. O'Reilly, N. Betts, C. C. Patterson, G. Davey Smith, and A. E. Evans.** 2000. "Season and Outdoor Ambient Temperature: Effects on Birth Weight." *Obstetrics and Gynecology*, 96(5): 689–95.
- National Center for Atmospheric Research.** 2007. Community Climate System Model. <http://www.cgd.ucar.edu/csm/> (accessed May 2007).
- ▶ **Royer, Heather.** 2009. "Separated at Girth: US Twin Estimates of the Effects of Birth Weight." *American Economic Journal: Applied Economics*, 1(1): 49–85.
- ▶ **Tol, Richard S. J.** 2002a. "Estimates of the Damage Costs of Climate Change. Part I: Benchmark Estimates." *Environmental and Resource Economics*, 21(1): 47–73.
- ▶ **Tol, Richard S. J.** 2002b. "Estimates of the Damage Costs of Climate Change: Part II. Dynamic Estimates." *Environmental and Resource Economics*, 21(2): 135–60.