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Maternal exposure to heatwave and birth outcomes: Evidence from sub-Saharan Africa

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Introduction

Intrauterine shocks can adversely affect health at birth (Almond & Currie, 2011; Torche, 2011), and this can in turn affect the development and well-being during childhood and adulthood (Conley et al., 2003). Previous literature suggests that in-utero shocks have more severe and longer-lasting effects than those occurring during early childhood (Almond & Currie, 2011). Specifically, shocks affecting pregnant women can have long-lasting effects on the health, education, and socioeconomic outcomes of their offspring (Almond, 2006; Song, 2013; Torche, 2011) and of the children of their offspring (Cook et al., 2019; Lee, 2014). This study focuses on one such shock—in-utero exposure to heatwave—and its effect on infants' birthweight in sub-Saharan Africa (SSA). Using high-resolution climate daily data on heatwave events, and applying a difference-in-difference methodology, I find that infants exposed to heatwave in the second trimester of gestation had significantly lower birthweight and reduced gestational age than those unexposed or exposed earlier or later in the pregnancy.

Given concerns of global warming, researchers have increasingly considered the role that climate variability and extreme climate-related events have on birth outcomes. Heatwaves in particular are considered one of the most important global public health challenges of this century given that they are projected to increase in frequency, intensity, and duration in most parts of the world (IPCC, 2014, 2019). Investigating the impact of heatwave on birthweight is important for two main reasons. First, the effects of such events are more amenable to policy interventions. Second, birthweight is a marker of early health status, it has effects on the development and well-being during childhood and adulthood, and its negative effects can be transmitted to the next generations. In particular, low birthweight and preterm birth are leading causes of neonatal and infant mortality as well as risk factors for stunted growth during childhood (Christian et al., 2013; UNICEF & WHO, 2019; WHO, 2005). Birthweight is correlated with chronic diseases in adulthood, including hypertension, coronary heart disease, obesity, and diabetes (Barker, 2004; Jornayvaz et al., 2016). Birthweight is correlated with more than health outcomes. Previous studies show a positive association between birthweight and early cognitive and development outcomes, educational attainment, employment, and earnings (Boardman et al., 2002; Case et al., 2005; Conley & Bennett, 2000; Currie & Hyson, 1999; Gu et al., 2017). Finally, the negative effects of birthweight are not restricted to one generation only, but they can persist intergenerationally: prior research finds that mothers with low birthweight are significantly more likely to have low birthweight babies (Currie & Moretti, 2007). This relationship between birthweight and short- and long-run health, education, and socioeconomic outcomes suggests that if heatwave reduces birthweight, its impact may affect population health and well-being in unprecedented ways in coming decades. This could particularly be the case in poor contexts where people are disproportionately vulnerable to climate extremes, which are expected to increase in frequency, intensity, and duration as a consequence of the overall global warning (IPCC, 2014, 2019).

Previous studies are limited in two important ways that restrict our understanding of how in-utero exposure to climate extremes impacts birthweight. First, they mainly focus on maternal exposure to hot days (Davenport et al., 2020; Deschênes et al., 2009; Grace et al., 2015, 2021) or positive rainfall shocks (Rocha & Soares, 2015) thus overlooking the effects of heatwave. The only study examining the effects of maternal exposure to heatwave on birthweight is from a Latin American context (Andalón et al., 2016), thus it is unclear whether the results would generalise to

SSA: a largely rural and agrarian context that is highly vulnerable to heatwave, and with a high incidence of low birthweight. Additionally, this one study uses administrative data from the Colombian national registry of live births which is particularly limiting, especially in the SSA context where this type of data is not available yet. Leveraging detailed information on birth and pregnancy outcomes only recently made available in the Demographic and Health Surveys (DHS), it is possible to create for the first time in the SSA context correct measures of exposure during the gestation period and thus examine these effects.

Second, there is no prior evidence on the mechanisms underlying the heatwave effects on birthweight. Low birthweight is caused by two distinct mechanisms—reduced gestational age or intrauterine growth restriction (IUGR, also referred to as small-for-gestational-age) or a combination of both (Kramer, 1987a, 1987b)—which differ in aetiology and long-term consequences (Hobel et al., 2008; Paneth, 1995). A growing literature argues that the negative effects of maternal exposure to stress on birthweight mainly operate through reduced gestational age (Torche, 2011) and that the effects of undernutrition and diseases in pregnancy are often reflected in IUGR (Almond et al., 2011; Almond & Mazumder, 2011; Hoynes et al., 2011; Newman et al., 2019). Previous research finds that in-utero exposure to heatwave reduces the probability of full-term pregnancy (Andalón et al., 2016), but none of the current studies have systematically examined these two mechanisms.

This study aims to fill these gaps in our current knowledge about the in-utero exposure to heatwave on birthweight by addressing two poorly understood questions about the *timing* and *mechanism* of heatwave effects. To do so, I leverage georeferenced survey data from the DHS that allow to link the birth outcomes of 64,208 infants across eleven SSA countries with fine-grained climate daily data on heatwave events to provide the first evidence on the causal impacts of in-utero exposure to heatwave on birthweight in SSA. By doing so, this study informs when during the gestation (first, second, and third trimesters) heatwave is more consequential, and the extent to which gestational age and uterine growth contribute to the effect of heatwave exposure on birthweight.

Data and variables

I combine datasets from two sources: (1) georeferenced micro-level health and socioeconomic data from the Demographic and Health Surveys (DHS), and (2) georeferenced climate data from the ERA5 archive provided by the European Centre for Medium-Term Weather Forecasting (ECMWF).

All DHS from the latest phase (Phase VII) available in early 2020 that contain information on the woman's geographic location (i.e. GPS latitude and longitude coordinates) and time of residence in the cluster are employed: Angola 2015, Benin 2017, Burundi 2016, Ethiopia 2016, Malawi 2015, Mali 2018, Nigeria 2018, South Africa 2016, Uganda 2016, Zambia 2018, and Zimbabwe 2015.

The climate data set retrieved from the ECMWF's ERA5 archive contains data for every hour since 1 January 1979 on a global grid of parallels and meridians at a 0.25 × 0.25-degree resolution—about 30 km at the equator. I extract data on maximum air temperature for every hour from 1 January 1979 to 31 December 2019 and for every weather grid cell (ERA5 cells) across all the 11 SSA countries. These data are then used to calculate heatwave events across DHS clusters, as discussed below.

Dependent variables

The dependent variables used in the analysis are birthweight measured in grams, gestational age measured in months, and uterine growth measured as the gestational age–specific birthweight percentile (using separate birthweight distributions by sex). In an alternative specification, these variables are dichotomised to produce measures of low birthweight (<2,500 grams), preterm delivery (<9 months), and intrauterine growth restriction (birthweight below the 10th percentile of the weight distribution by gestational age).

Treatment variable

The main treatment is whether or not the child was exposed to heatwave during each trimester of gestation, constructed as 1 to 12 weeks after conception for the first trimester, 13 to 26 weeks after conception for the second trimester, and 27 to 40 weeks after conception for the third trimester. In the literature, a heatwave is often defined as two or more consecutive days with temperature above a certain temperature cut-off for a specific study period, which I follow in this work.

For each child conceived in DHS cluster e at time t, I create a binary variable for the treatment that equals '1' if the daily maximum temperature exceeds the 99th centile of daily maximum temperature for four or more consecutive days during each trimester of gestation. The 99th centile of daily maximum temperature is based on each cluster's own distribution of maximum temperature over the period between 1 January 1979 and 31 December 2019 and is thus location specific. I use location-specific threshold value because it is important to consider that each location has its own distribution of maximum temperature to understand the nature of the shock. In further analyses, I also allow for flexibility in the definition of heatwave to explore the effects of different degrees of intensity of heatwave.

Summary statistics

The sample is composed of 64,208 children conceived between October 2009 and May 2018 to 49,935 women living across 6,536 clusters. Data are weighted using DHS sample weights. The mean birthweight in the sample is 3,219 g. About 10.5% of the children weighted less than 2500 g at birth, 6.4% were born prematurely, and 10.6% had a birthweight below the 10th percentile of the weight distribution. Thirty percent of the children were exposed to a heatwave during at least one trimester of gestation.

Methodology

The main analysis of this paper is to assess the effect of *in utero* exposure to heatwave on birthweight and the mechanisms underlying this effect, which I do using a difference-in-differences identification strategy following the approach of Torche and Villarreal (2014) and Foureaux Koppensteiner and Manacorda (2016). The strategy exploits: (1) the exogeneity of weather events (Andriano & Behrman, 2020; Harari & La Ferrara, 2018; von Uexkull et al., 2016), and (2) the differential changes in heatwave exposure and birthweight across very small geographical areas (i.e. DHS clusters) over time. The latter provides a way to control for unobserved time-invariant cluster characteristics and to subsume aggregate time effects, and is employed to estimate causal effects of climate extremes. I estimate the following model:

$$y_{iets} = \beta_0 + \beta_1 first\ trimester_{et} + \beta_2 second\ trimester_{et} + \beta_3 third\ trimester_{et} + x'_{it}\beta_4 + \alpha_e + \alpha_t + \alpha_s + \varepsilon_{iets}, \quad \text{Eq. (1)}$$

where y_{iets} is the individual outcome variable (birthweight, gestational age, uterine growth, etc.) from ERA5 cell e at time t available in survey s; $first\ trimester_{et}$, $second\ trimester_{et}$, and $third\ trimester_{et}$ are exposure to heatwave during the first, second, and third trimester, respectively; α_e and α_t are respectively the fixed effects for the mother's ERA5 cell of residence and for month of conception, where the latter is a variable running from 1 for the first month of conception (April 2010) to 104 for the last month of conception (September 2017); x'_{it} includes child and mother characteristics. The survey fixed effects, α_s, are used to account for potential differences across surveys; because there is no more than one survey per country, α_s also controls for differences across countries.

Results

Birthweight, gestational age, and uterine growth

I find that exposure in the second trimester results in significant declines in birthweight; exposure in the first and third trimester does not have any significant effect on birthweight. Being exposed to heatwave during the second trimester leads to significant declines in birthweight by 21.4 g.

As discussed, the effect of heatwave exposure on birthweight depends on only two proximate determinants of birthweight: gestational age and uterine growth. In order to explore them, the effect of heatwave on gestational age and gestational age–specific birthweight percentile is examined. I find a significant decline in gestational age focused on the second trimester of gestation, whereas exposure in the first and third trimester does not have any significant effect on gestational age. These results suggest that the effect of exposure to heatwave on birthweight is at least partly driven by a reduction in gestational age.

The results on uterine growth indicate a small and statistically insignificant decline in uterine growth among babies exposed to heatwave in the second trimester. As a whole, these results support the hypothesis that the influence of heatwave exposure on birthweight is largely mediated by reduced gestational age.

Low birthweight, preterm delivery, and intrauterine growth restriction

The previous section has shown that exposure to heatwave during the second trimester significantly reduces birthweight by 21.4 g, and this effect appears to be largely mediated by reduced gestational age. It could be that the exposure has altered birthweight within a plausible optimal range, without affecting the proportion of low-weight infants most vulnerable to health and developmental problems. I show that this is not the case. To address this question, I examine the effects on low birthweight, preterm delivery, and intrauterine growth restriction across the three periods of exposure.

I find that the probability of low birthweight increases by 0.9% among children exposed during the second trimester of gestation, but not in the other periods of gestation. I also find an increase of 1.3% in the probability of preterm birth for children exposed during the second trimester of gestation. Finally, exposure in any of the gestation periods does not significantly affect the probability of IUGR. These findings have two important implications. First, they are consistent with the hypothesis that the effect of exposure to heatwave on birthweight is mainly driven by an increased probability of preterm delivery. Second, they indicate that exposure to heatwave in late pregnancy does not simply move mean birthweight within a plausibly optimal range, but rather increases the proportion of births most at risk of poor health and developmental outcomes.

Robustness and sensitivity analyses

In further analyses, I conduct a number of robustness and sensitivity analyses and discuss potential sources of selectivity that may bias the effect of heatwave on birthweight. Compared to other environmental shocks and policy interventions, the decline of birthweight of 21.4 grams due to heatwave exposure in the second trimester I find is substantively relevant.

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