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Extreme Heat, Birth Outcomes, and Socioeconomic Heterogeneity

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ABSTRACT We investigate the effect of extreme heat on birth outcomes and how this effect may vary by family socioeconomic status (SES). We create a detailed data set by linking individual-level data on approximately 4 million newborns in Spanish provincial capitals between 1990 and 2016 with precise meteorological data on the temperatures children experienced throughout their gestation. The outcomes are preterm birth, low birth weight, and very low birth weight. Socioeconomic status is assessed using parents' highest occupational level. We find that the incidence of negative birth outcomes increased for children exposed to extreme heat in early gestation. Further, the effect is concentrated mostly among children from a low socioeconomic background. Given the importance of birth outcomes for the next generation's well-being, our results highlight the potential contributions of extreme temperatures to the widening of preexisting socioeconomic inequalities. The forecasted increase in extreme climatic events makes the results of this study concerning, especially for low-SES children.

KEYWORDS Temperature • Birth outcomes • SES inequalities

Introduction

The average global temperature has risen by approximately 1.5ºC since the preindustrial period (Cramer et al. 2018), and climate forecasters expect even more severe increases in the coming decades (Beniston et al. 2007; Fischer et al. 2012). Concerns about rising global temperatures have stimulated research on the consequences of climatic conditions. A growing body of research has been investigating the consequences of extreme temperatures, seasonality, and meteorological phenomena on a broad array of social outcomes, such as income, mortality, morbidity, fertility, cognitive ability, educational achievement, mental health, and birth outcomes (Barreca et al. 2018; Currie and Rossin-Slater 2013; Dell et al. 2014; de Oliveira et al. 2021; Deschênes et al. 2009; Isen et al. 2017; Wilde et al. 2017).

In this article, we provide novel evidence on the consequences of extreme heat on birth outcomes and its variations across socioeconomic groups. We ask two research questions. First, does extreme heat during gestation affect birth outcomes? Second,

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is the effect of extreme heat stratified by parental socioeconomic status (SES)? To address these questions, we create an exhaustive data set. We link individual-level data on approximately 4 million newborns in Spanish provincial capitals between 1990 and 2016 with precise meteorological data on the temperatures children experienced throughout gestation.

The prenatal period may have lifelong implications. It represents a sensitive stage of human development, and even small adverse events while in the womb may have profound consequences on fetal development and birth outcomes (Almond and Currie 2011; Almond et al. 2018; Barker 1990), which influence children's future well-being (Black et al. 2007; Härkönen et al. 2012; Palloni 2006; Torche 2018). Climate affects birth outcomes: prolonged exposure to extreme heat *in utero* may compromise fetal growth, increasing the incidence of adverse birth outcomes, such as low birth weight (LBW) and preterm birth (PTB) (Chen et al. 2020; Deschênes et al. 2009).

Yet, less is known about whether these consequences are the same for children from different socioeconomic backgrounds. Three large review studies on the consequence of climate on birth outcomes identified only a handful of studies investigating whether SES moderates the adverse consequences of extreme temperatures on birth outcomes (Bekkar et al. 2020; Chersich et al. 2020; Zhang et al. 2017). Further, these studies led to mixed results. Four studies found that low-SES children are more vulnerable to extreme temperatures in China, Vietnam, and New York City (Chen et al. 2020; Le and Nguyen 2021; Liu et al. 2022; Ngo and Horton 2016). By contrast, one article found no clear heterogeneous effect in Seoul, Korea (Son et al. 2019), another found no differences in Hungary (Hajdu and Hajdu 2021), and yet another found a larger risk among socially advantaged mothers in California (Basu et al. 2018).

Our study builds on this literature and contributes in several ways to the understanding of the heterogeneous effect of extreme heat on birth outcomes. First, whereas most previous studies focused on a single measure of birth outcomes, we study multiple indicators: LBW, PTB, and very low birth weight (VLBW). Second, with two exceptions (Basu et al. 2018; Hajdu and Hajdu 2021), prior studies on extreme heat in urban populations focused on a single city. Here, we provide a comprehensive account of the heterogeneous effect of extreme heat on the Spanish urban population, studying all births over a 27-year period (1990–2016). Spain represents an interesting case study because average temperatures increased faster there than in other European countries (Cramer et al. 2018) and because it has significant cross-city variation in climatic conditions. Third, given the mixed results from developed countries (Basu et al. 2018; Hajdu and Hajdu 2021; Ngo and Horton 2016; Son et al. 2019), our comprehensive results from Spain provide new important, incremental evidence on the socioeconomic heterogeneity of the effect of extreme temperatures on birth outcomes. We believe that studying how the consequences of climatic events interact with SES is an important way to comprehend how climate change could shape socioeconomic inequalities in the future. Moreover, we contribute to the broader literature on the unequal consequences of disruptive life events and their stratification by SES in a population (Aquino et al. 2022; Bernardi 2014; Conley 2008).

Background

Extreme Temperatures and Birth Outcomes: Biological Mechanisms

Changing climatic conditions, particularly extreme heat, may expose mothers and fetuses to new environmental stressors, harming maternal well-being and fetal development. First and foremost, pregnant women experience hormonal, metabolic, and anatomical changes that cause physical strain and make them more susceptible to extreme climatic conditions (Chersich et al. 2020; Laburn 1996; Wells 2002). These maternal characteristics translate into vulnerabilities for the fetus, whose ability to absorb and dissipate heat depends entirely on the mother: approximately 85% relies on maternal blood circulation, and the remaining 15% depends on amniotic fluids and the placental walls (Laburn 1996; Polin et al. 2011).

Extreme heat can lead to maternal hyperthermia, which has been shown to have teratogenic effects,[1] leading to birth defects. In animal studies on guinea pigs, a heatwave in the 1960s was linked to miscarriages as well as birth defects, such as microcephaly, anencephaly, reduced limb length, and heart and renal defects (Edwards 1998; Graham 2005). In human studies, the teratogenic effects of maternal hyperthermia are more mixed. Some studies linked prolonged exposure to saunas and hot tubs to birth defects (Duong et al. 2011; Milunsky et al. 1992), whereas other studies contested these findings (e.g., Ravanelli et al. 2019). Maternal hyperthermia seems to be linked to gestational anomalies through the disruption of protein conformation and function among developing tissues (Polin et al. 2011). Fetal hyperthermia is also likely to occur because the fetus' rapidly forming tissues produce a large amount of heat—approximately twice the amount that adult tissues produce (Laburn 1996). Fetal brain development is one of the most heat-producing processes during fetal formation, but brain tissues are also those more sensitive to heat (Laburn 1996). Maternal hyperthermia is also linked to intrauterine fetal growth restriction through placental deficiencies, such as reduced uterine and umbilical blood flow (Regnault et al. 2005). There is no complete consensus on how prolonged such heat exposure has to be to lead to fetal health insults. Both a body temperature increase beyond 2°C for more than an hour and prolonged milder body temperature increases (i.e., 0.6°C) trigger adverse effects (Regnault et al. 2005).

Medical literature on gestational hyperthermia suggests that the pregnancy stage at which extreme heat exposure occurs matters for fetal development. The teratogenic effects of early-pregnancy hyperthermia on limbs and other organs have been documented (Graham 2005; Polin et al. 2011). Similarly, animal studies also found that heat exposure is linked with intrauterine growth restrictions in the first and second trimesters of gestation (Bell et al. 1987; Regnault et al. 2005). Yet, the epidemiological and social science literature on the effect of heat on birth outcomes has produced mixed results on trimester sensitivity: some studies found larger estimates in the first and second trimesters (Cho 2020; Ngo and Horton 2016), and others found larger estimates in the second and third trimesters (Chen et al. 2020; Deschênes et al. 2009;

[1] That is, hyperthermia may affect cell and tissue development in the fetus.

Hajdu and Hajdu 2021). These differences may be related to a failure to account for selective mortality of fetuses exposed in early pregnancy (Bruckner and Catalano 2018; Hajdu and Hajdu 2021).

SES and the Stratified Effect of Extreme Heat

Some studies on the effect of extreme heat on birth outcomes investigated potential variation across population subgroups. For example, in their seminal work, Deschênes et al. (2009) found differences across racial groups in the United States. Other studies found differences in the effect of extreme heat by maternal age, maternal body mass index (BMI), and smoking and alcohol consumption (for a review, see Zhang et al. 2017). Here, we focus on SES because its interaction with climatic conditions may have implications for how future climate change could affect the intergenerational transmission of SES across generations and, more generally, socioeconomic inequalities.

Whether SES could buffer the effect of prenatal exposure to extreme heat is an open question. Theoretical debate centers on whether parents recognize that a particular event could harm the fetus and whether they will respond to this possible insult (Almond and Mazumder 2013). Empirical studies investigating prenatal health insults have found mixed results regarding whether prenatal adverse exposures are mitigated by SES (Torche and Conley 2016).[2] In this section, we outline at least three sets of mechanisms that may lead to a stratified effect of extreme temperatures: (1) differential exposure, (2) differential resources, and (3) differential susceptibility.

First, differential exposure occurs when conditions related to a mother's socioeconomic background reduce or exacerbate her exposure to extreme temperatures. Housing conditions vary based on socioeconomic background. For example, high-SES individuals are more likely to inhabit the coolest and greenest areas of a city (Taylor et al. 2018). Further, SES influences access to cooling technologies. Low-SES individuals may be less likely to purchase air conditioning and properly insulate their homes owing to monetary constraints. Finally, SES-related work environments and occupational characteristics may influence the effect of extreme temperatures. On the one hand, workers in manual occupations (e.g., agricultural work, construction) and those working in bakeries, restaurants, and laundries conduct physically intense tasks in hot and often poorly ventilated areas (Varghese et al. 2018). Such workers are therefore the most exposed to heat-related risks. On the other hand, white-collar workers are the least at risk; they do not perform strenuous physical work and are often provided with air conditioning and proper insulation to protect them from uncomfortable temperatures in the workplace. White-collar workers are also likely to have more control over their work schedules, enabling them to avoid risks related to extremely hot weather. Also, higher wages and appropriate work contracts

[2] For example, some studies suggested that SES mitigates the effects of prenatal maternal stress (Brown 2018; Cozzani et al. 2022; Duncan et al. 2017). By contrast, other studies found null results (Brown 2020; Persson and Rossin-Slater 2018), and one study found an opposite effect (Torche and Villarreal 2014). Nonetheless, each stressor (e.g., stress, pollution, temperatures) may have its own specific mechanisms, which may or may not be moderated by parental SES.

may confer other benefits to white-collar workers. For instance, they may be able to spend long summer vacations in milder areas to avoid extremely hot summers, or they may use private means of transportation rather than the more crowded (and therefore hotter) public ones.

Second, SES-related cultural and social coping resources may moderate the effect of extreme heat. For example, higher SES individuals achieve, on average, more years of education and have a better grasp of crucial health knowledge (Abel 2008), which may lead them to choose less risky behaviors during high temperatures. They may also have access to more social support, allowing pregnant women to avoid strenuous tasks, such as long errands on very hot days (Kawachi et al. 1997; Pampel et al. 2010).

Third, differential susceptibility (Forastiere et al. 2007; Liu et al. 2022) is another channel through which extreme heat may have a stratified effect on a population. SES shapes inequalities in health and morbidity (Mackenbach et al. 2008). Lower status individuals have, on average, higher BMI and a higher incidence of cardiovascular diseases and diabetes (Basto-Abreu et al. 2018; Schultz et al. 2018); these relationships also hold for pregnant women (Baron et al. 2015). Because extreme temperatures are more detrimental for individuals with a preexisting medical condition (Kovats and Hajat 2008), lower SES women and their offspring may be more susceptible to extreme climatic events.

Spanish Climate, Extreme Events, and Forecast

Spain's Mediterranean climate is characterized by temperate, rainy winters and warm, dry summers (Lionello et al. 2006). However, its provinces demonstrate significant climate differences: the north is colder and rainier than the south. Figure 1 displays the average yearly temperatures (1990–2016) for each Spanish province capital in our empirical analysis. Mean temperatures vary from approximately 10°C (50°F) in the north to 20°C (68°F) in the south, denoting geographic variability.

In the last decades, the Spanish Mediterranean climate has been unstable and affected by climate change, becoming warmer more quickly than in other European countries (Cramer et al. 2018; Fischer et al. 2012; Perkins-Kirkpatrick and Lewis 2020). A notable example is 2003, which saw the hottest summer in Europe since 1500 AD (Stott et al. 2004). Climatic projections forecast a future intensification of extreme phenomena. For example, climate forecasters expect a 20-fold increase in hot days in the Iberian Peninsula in 2071–2100 compared with 1961–1991 (Fischer et al. 2012).

Data, Variables, and Methods

Spanish Birth Certificates

To estimate the effect of extreme temperatures on birth outcomes, we combine individual-level information from Spanish birth certificates with detailed meteorological data. The Spanish birth certificates, provided by the Spanish National Statistical

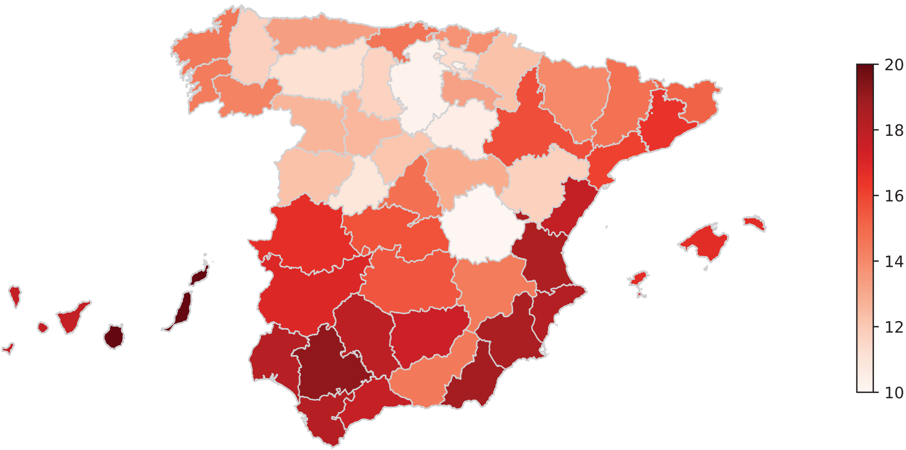

Fig. 1 Average temperature by Spanish provincial capitals, 1990–2016. The color in each province refers to the average of its provincial capital. The legend is reported in Celsius, with a Fahrenheit range of 50°F–68°F.

Institute (*Instituto Nacional de Estadistica*, INE), are administrative data covering the universe of newborns in Spain every year. The data are collected from the birth certificates submitted by a parent of the child at the time of the newborn's inscription in the civil register. The certificates contain anthropometric measures of children that are consistent with hospital records, especially for frail deliveries (Juárez et al. 2012).

We include only children born in a provincial capital between 1990 and 2016. This restriction allows us to combine birth certificate data with precise meteorological data. The final, largest analytic population consists of 4,314,381 singleton births (more than 40% of the newborn population in Spain in the period considered).

We combine births with meteorological data from the date of conception, with an approach similar to Deschênes et al.'s (2009). Because precise birthdates are not available, we assume that all children were born in the middle of the month; we then count backward to the month of conception using gestational age. This strategy is preferable because birthdate may be an outcome of temperature (Currie and Rossin-Slater 2013; Deschênes et al. 2009).

Meteorological Data

We draw on the E-OBS daily gridded meteorological data available in the Copernicus Climate Data Store (https://cds.climate.copernicus.eu/#!/home). Several European meteorological institutions and universities gather environmental observations on-site, which meteorologists used to construct these gridded values (Cornes et al. 2018). This data set contains accurate and complete historical climatic data from 1950 to 2020 with high spatial resolution for many countries in Europe and the Mediterranean area. The data for Spain are daily temperatures that numerous climatic stations collect and interpolate for the whole country (Cornes et al. 2018). We use the gridded meteorological data to extract the temperature estimates for areas closest to the center of the provincial capital. Additionally, we extract available information on other climatic variables: average precipitation, relative humidity, wind speed, and solar radiation. Total precipitation is the daily millimeters of rain, snow, and hail. Humidity, measured in percentages, denotes the relative humidity each day; 100% indicates that the air is saturated with water. Wind speed is measured in meters per second. Surface shortwave downwelling radiation is a measure of solar radiation calculated in watts per square meter.

Variables

We use three birth outcomes as dependent variables. First, PTB indicates whether a child is born before the 37th week of gestation. This variable, measured separately from gestational age in weeks, has no missing values because the INE imputes them; in approximately 12% of cases, gestational age in weeks is missing.[3] Second, LBW (<2,500 grams) is a parental report at the time of the inscription in the civil register. A study comparing the report in the registers with hospital records found that data are accurate for frail deliveries (i.e., PTB and LBW; Juárez et al. 2012). Third, we measure whether the child had VLBW (<1,500 grams). Following common practice in the literature, we focus on binary indicators for PTB, LBW, and VLBW because they are good predictors of fetal environment, fetal health impairments, and future developmental potential (Boardman et al. 2002; Torche and Conley 2016).

The main independent variables are temperature bins counting the number of days within a range of mean temperatures by trimester: cold days (<5°C/<41°F); days in the comfort zone (5°C–25°C/41F°–77°F); warm days (>25°C–32°C/>77°F–89.6°F); and hot/extremely hot days (>32°C/>89.6°F). These bins resemble those adopted in the literature (Barreca et al. 2016; Cho 2020; Hovdahl 2020). However, in sensitivity analyses using different measures of temperatures, we find consistent results (discussed later). The reference category in the models is 5°C–25°C (the comfort zone): the results can be interpreted as the effect of an extra day with extreme temperatures relative to a day in the comfort zone.

Our key stratifying variable is the highest SES among parents, measured as the highest occupational level of the mother and father. In the years covered in our study, the only comparable measure of SES provided on birth certificates is maternal and paternal occupation, measured by the one-digit International Standard Classification of Occupations (ISCO) 1968 and 1988. To ensure comparability between the 1968 and 1988 ISCO measurements, we categorize parents as high, medium, and low SES by relying on the average International Socio-economic Index of occupational status (ISEI) score of each ISCO one-digit category (Ganzeboom and Treiman 1996). Those with high SES have an ISEI of 60 or above, medium SES indicates an ISEI of 40–59, and low SES is an ISEI below 39.

For 1990–2006, SES is measured by ISCO-68 in 12 categories: (1) professionals, technicians, and associate professionals; (2) managers and legislators; (3) clerical

[3] We replicated analyses without those cases, and the results were fully consistent with those presented in the main text (see Table S1, online appendix).

support workers; (4) salesman and shop owners; (5) sales and services elementary occupations; (6) agricultural, forestry, and fishery workers; (7) production workers, trade workers, and plant and machine operators; (8) army; (9) students; (10) unpaid houseworkers; (11) retired; and (12) no information. We code the 12 categories into three broad groups: high SES includes categories 1 and 2; medium SES is categories 3 and 4; and low SES is categories 5, 6, and 7. We also create a category for stay-at-home mothers, which includes category 10; inactive/no information covers categories 11 and 12.

For 2007–2016, SES is assessed with the ISCO-88 in 14 categories: (1) legislators, senior officials, and managers; (2) professionals; (3) technicians and associate professionals; (4) clerks; (5) service and shop and market sales workers; (6) skilled agricultural and fishery workers; (7) craft and related trade workers; (8) plant and machine operators; (9) elementary occupations; (10) students; (11) unpaid houseworkers; (12) inactive; (13) army; and (14) no information. In this case, high SES is indicated by categories 1 and 2, medium SES is categories 3 and 4, low SES is indicated by categories 5–9, stay-at-home mothers are category 11, and inactive/no information is categories 12–14. In the pooled analysis, we also include births to inactive/no-information parents. In the heterogeneous analyses, we focus on high-, medium-, and low-SES measures across parents. Moreover, we also provide supplementary analyses using maternal education, which is available for 2007–2016; the results are consistent with those presented in the main text.

We include mother, child, contextual, and climatic controls in the analyses. Mother and child controls include mother's age and mother's age squared, the newborn's sex, whether the child is the firstborn, mother's marital status, and migration background that we capture with a binary variable indicating whether the mother has a non-Spanish background (0 = native Spanish; 1 = non-Spanish). Contextual controls are the share of females participating in the labor force, the province-cohort share of females with tertiary education, population density, the logarithm of the provincial GDP per capita, and vegetation's leaf area index. Climatic controls are solar radiation, average precipitation, wind speed, and relative humidity.

Empirical Strategy

To estimate the effect of extreme temperatures on birth outcomes, we compute linear probability models. When we investigate the heterogeneous effect, we estimate the models separately by SES. We define the model as follows:

$$P(Y=1)_i = \sum_j \theta_j^{TR1} \boldsymbol{TBINTR1}_{pym}^j + \sum_j \theta_j^{TR2} \boldsymbol{TBINTR2}_{pym}^j + \sum_j \theta_j^{TR3} \boldsymbol{TBINTR3}_{pym}^j + \boldsymbol{\theta X}_i + \alpha_{py} + \gamma_{pt} + \delta_m + \varepsilon_i, \quad (1)$$

where i denotes the individual; p, y, and m are the province, year, and month of conception, respectively; and j is an index of the four mean temperature bins. $P(Y=1)_i$ is the probability that a given birth outcome equals 1. $\boldsymbol{TBINTR1}$ are the temperature bins (defined as specified earlier) that a child experienced in the first trimester (*TR1*) of gestation; $\boldsymbol{TBINTR2}$ and $\boldsymbol{TBINTR3}$ are the respective variables representing the second and third trimesters. $\mathbf{X}_i$ is a vector of control variables (defined earlier). α_{py} accounts for province × year trends, γ_{pt} is the province × polynomial quadratic in the year-month of conception time trend, and δ_m is the conception month fixed effects. More precisely, the province × year fixed effects allow us to capture the 50 provincial capital–specific yearly variations in factors such as economic growth over the 27 years of our analysis. The province × polynomial quadratic in the year-month of conception time trend and conception month fixed effects allow us to account for the province's specific seasonal trends. Results are also robust to alternative fixed-effects specifications (discussed later). The standard errors are clustered at the provincial capital level. Because of the unpredictability of extreme weather conditions, we expect the effect of temperature to be orthogonal to other factors affecting birth outcomes. Our results are unchanged by the inclusion of the large set of control variables mentioned earlier (results available upon request).

Results

Descriptive Statistics

To contextualize our analyses, we show in Table 1 the distribution of variables by parental SES. In the period considered (January 1990–December 2016), we find no substantive differences in exposure to hot days (>32°C/>89.6°F), which averages between 0.31 and 0.35 days of pregnancy across SES groups. Although the number of hot days seems rather small, approximately 10% of our analytic sample (N=423,221) experienced at least one day above 32°C during gestation.

Newborns show a negative gradient in birth outcomes across parental SES groups. The prevalence of PTB is approximately 5.8% for high-SES offspring and increases to 7.7% for low-SES offspring. Similar differences by SES are observed for the incidence of LBW: 4.7%, 5.5%, and 6.7% for high-, medium-, and low-SES children, respectively. Approximately 0.5% of high-SES offspring have VLBW, compared with 0.9% for low-SES offspring.

The Effect of Extreme Temperatures on Birth Outcomes by SES, Trimester, and Newborn's Sex

In this section, we describe our results for the effect of extreme heat during the entire gestational period on birth outcomes in the full sample and by SES. We also describe the results by trimester of gestation and by newborn's sex.

Table 2 displays the results for the full sample and by SES for the effect of temperatures across the entire gestational period on the likelihood of PTB, LBW, and VLBW. The coefficients presented in the table are multiplied by 100; they can be interpreted as the percentage-point change in a certain birth outcome with an additional day falling within a certain temperature bin relative to being in the reference bin.

In the full sample (columns 1–3), we observe a nonsignificant increase in LBW and VLBW for each additional day above 32°C (89.6°F) relative to the comfort zone, and we do not observe any increase in PTB. We observe a heterogeneous effect of extreme heat by SES (columns 4–12). An additional day above 32°C (89.6°F) relative to the

Table 1 Descriptive statistics

	High SES		Medium SES		Low SES	
	Mean %	*N* (SD)	Mean %	*N* (SD)	Mean %	*N* (SD)
Birth Outcomes						
PTB	5.77	85,618	6.39	73,238	7.72	100,527
LBW[a]	4.74	68,611	5.45	60,664	6.74	84,158
VLBW[a]	0.54	7,743	0.64	7,178	0.85	10,648
Newborn						
Sex (male)	51.64	873,722	51.62	723,225	51.58	671,425
Firstborn	54.15	803,006	56.95	652,735	50.64	659,191
Mother						
Mother is married	95.4	1,614,298	78.06	894,598	64.61	841,018
Mother's age	33.19	(4.18)	31.91	(4.75)	29.49	(5.62)
Non-Spanish	4.6	77,767	5.68	65,086	18.11	235,803
Contextual Characteristics						
Female employment	0.44	(0.11)	0.43	(0.11)	0.43	(0.11)
Share of females with tertiary degree	0.39	(0.11)	0.39	(0.13)	0.39	(0.13)
Population density (per km^2)	348.44	(291.80)	295.63	(279.01)	239.70	(256.40)
ln(GDP)	10.33	(1.31)	10.12	(1.28)	9.84	(1.30)
Vegetation's leaf area index (m^2/m^2)	2.01	(0.79)	2.06	(0.69)	2.04	(0.82)
Climate						
Solar radiation (W/m^2)	1,017	(4.35)	1,017	(4.35)	1,017	(4.32)
Relative humidity (%)	66.25	(11.91)	66.50	(11.64)	67.01	(11.26)
Precipitation (mm/day)	1.34	(1.48)	1.29	(1.45)	1.28	(1.46)
Wind speed (m/sec)	0.36	(0.90)	0.34	(0.94)	0.31	(0.98)
Temperature						
Cold days (<5°C/<41°F)	13.11	(17.55)	13.08	(19)	12.88	(19.15)
Comfort zone (5°C–25°C/41°F–77°F)	228.36	(26.42)	227.77	(26.50)	227.94	(26.88)
Warm days (>25°C–32°C/>77°F–89.6°F)	32.14	(25.7)	32.74	(26.11)	26.72	(26.72)
Hot days (>32°C/>89.6°F)	0.31	(1.39)	0.33	(1.42)	0.35	(1.42)
% SES	37.73	1,482,984	29.16	1,146,060	33.12	1,301,743

Notes: Descriptive statistics are displayed by SES and exclude those without SES information and those who are inactive. These statistics are computed on the largest sample for each SES group. N=3,930,787.

[a] The overall number of observations for LBW and VLBW is 3,807,535 births.

comfort zone increases the risk of LBW and VLBW (β = 0.026 and β = 0.020, respectively; $p < .05$) only among low-SES newborns. We also observe a reduction in the risk of LBW for high-SES offspring (β = –0.28; $p < .05$), and we speculate that this decrease is related to protective behavior during extreme heat among high-SES parents (e.g., avoidance of carrying out activities in the heat). Additionally, we find that exposure to cold reduces the risk of adverse birth outcomes mostly for medium-SES (PTB:

Table 2 Linear probability models predicting the effect of temperatures on birth outcomes

	PTB	LBW	VLBW	PTB			LBW			VLBW		
	Full Sample (1)	Full Sample (2)	Full Sample (3)	High SES (4)	Med SES (5)	Low SES (6)	High SES (7)	Med SES (8)	Low SES (9)	High SES (10)	Med SES (11)	Low SES (12)
Days <5°C	−0.001	−0.004*	−0.001	0.002	−0.009*	0.005	−0.001	−0.007*	−0.004*	−0.001	−0.001	−0.001
	(0.002)	(0.002)	(0.000)	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Days >25°C–32°C	−0.001	−0.000	−0.000	0.002	0.001	−0.005*	0.001	−0.001	−0.001	−0.001	−0.001*	0.001
	(0.002)	(0.002)	(0.000)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Days >32°C	−0.026	0.016	0.006	−0.019	−0.033	−0.021	−0.028*	0.032	0.026*	−0.003	−0.002	0.020*
	(0.016)	(0.010)	(0.003)	(0.013)	(0.035)	(0.021)	(0.013)	(0.029)	(0.010)	(0.005)	(0.004)	(0.006)
N	4,314,381	4,152,395	4,152,395	1,482,984	1,146,060	1,301,743	1,446,251	1,113,128	1,248,156	1,446,251	1,113,128	1,248,156

Notes: The table presents estimated impacts of temperature on birth outcomes during the gestational period for the full sample and by parental SES. Temperature bins are cold days (<5°C/<41°F), days in the comfort zone (5°C–25°C/41°F–77°F), warm days (>25°C–32°C/>77°F–89.6°F), and hot days (>32°C/>89.6°F); the reference bin is the comfort zone (5°C–25°C). Robust standard errors, clustered at the provincial capital level, are shown in parentheses. Coefficients, scaled by 100 to enhance readability, can be interpreted as percentage-point changes in the specific birth outcome. Each model includes fixed effects for province × year of conception, the province-specific polynomial quadratic in the century-month of conception, and the month of conception. Demographic control variables include the newborn's sex, the mother's marital status, the mother's age, age squared, whether the child is the firstborn, and the mother's ethnic origin. Contextual controls are population density, the female employment rate, the logarithm of the provincial GDP, the provincial cohort–specific share of women with a tertiary degree, and vegetation's leaf area index. Climatic controls are relative humidity, solar radiation, wind speed, and average precipitation.

$^*p < .05$

β = −0.09, $p < .05$; LBW: β = −0.07, $p < .05$) and low-SES parents (LBW: β = −0.04; $p < .05$). However, the effect size of these coefficients is minuscule—at only a fraction of the coefficients for extreme heat. A possible explanation for the decrease in negative birth outcomes with temperatures below 5°C could be related to the broad availability of heating technologies that allow one to reduce the negative impact of cold spells and to increase the time spent indoors (Chirakijja et al. 2019).

Figure 2 displays the results of the effect of extreme heat (>32°C/>89.6°F) by SES and trimester of gestation; full results are presented in Table S2 in the online appendix. The figure displays the percentage-point change in birth outcomes and 95% confidence intervals for each additional day of extreme heat relative to the reference bin. Overall, we find that an additional day above 32°C (89.6°F) has a negative impact only on low- and medium-SES offspring, especially for such temperatures experienced in early pregnancy. For PTB, we do not find any statistically significant effect across all trimesters, except among low-SES offspring in the third trimester. For LBW, heat in the first trimester increases the risk of adverse birth outcomes for low- and medium-SES offspring (β = 0.033 and β = 0.047, respectively; $p < .05$). Heat in the second trimester increases the risk only for low-SES offspring (β = 0.085; $p < .05$), which also shows the highest magnitude in terms of effect size. For VLBW, low SES consistently shows the highest point estimates in the effect of extreme heat across all trimesters (β = 0.023, β = 0.023, and β = 0.017, for the first, second, and third trimesters, respectively), but only effects in the second and third trimester reach statistical significance at conventional levels ($p < .05$). We also compare coefficients for medium- and low-SES offspring with those of high-SES offspring using a formula for nonnested models (Clogg et al. 1995). All coefficients are statistically different ($p < .05$) except the coefficient on VLBW for low-SES offspring for the effect of heat in the first trimester.

Finally, because some studies highlighted the greater sensitivity of male fetuses to shocks *in utero* relative to females (DiPietro and Voegtline 2017; Fukuda et al. 2014), we replicated our analyses presented in Table 2 by the newborn's sex (see Figure S1, online appendix). Results show that extreme heat impacts the risk of LBW equally for low-SES males and females, but it has a larger impact on VLBW for males (β = 0.030; $p < .05$) than for females (β = −0.007; nonsignificant). These coefficients are statistically different ($p < .05$). Overall, newborn males appear to be slightly more affected by extreme heat while *in utero*.

Effects Size and Magnitude

The preceding discussion describes our coefficients in terms of their statistical significance. This practice has been criticized because the substantive significance of such findings is unclear (Bernardi et al. 2017; McCloskey and Ziliak 1996). We benchmark our estimates with results from previous research. To this aim, we compile a table of comparable studies using temperature bins to estimate the effect of heat on LBW, the most comparable outcome. Table 3 displays the summary of coefficient size (by SES, where possible) among our selection of studies. Research using temperature bins has found small changes in birth outcomes for one additional hot day, on the order of a fraction of a percentage point. Our baseline estimate for LBW is the lower bound

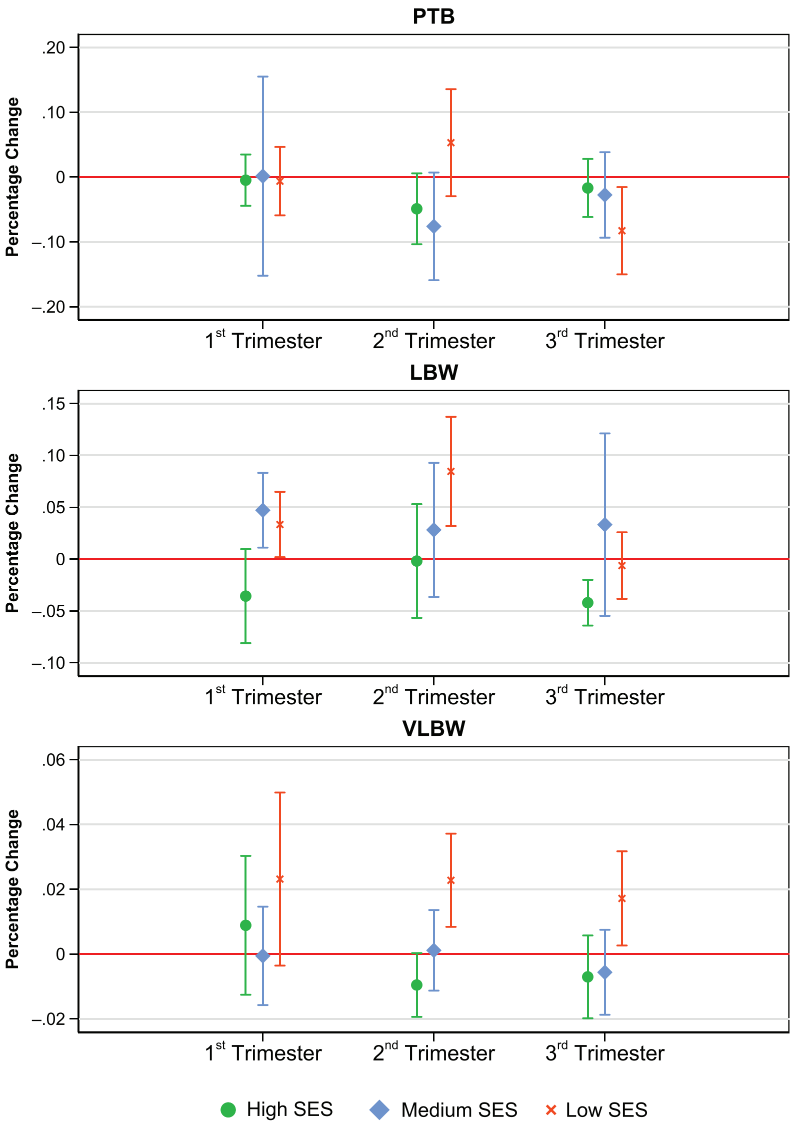

Fig. 2 Estimated effect of extreme heat (>32°C/>89.6°F) on birth outcomes, by SES and trimester of pregnancy. PTB = preterm birth. LBW = low birth weight. VLBW = very low birth weight. Estimates are obtained from Table S2 (online appendix), which also displays full estimates for other temperature bins. Coefficients, scaled by 100 to enhance readability, can be interpreted as percentage-point changes in the specific birth outcome. Each model includes fixed effects for province × year of conception, the province-specific polynomial quadratic in the century-month of conception, and the month of conception. Demographic control variables include the mother's marital status, the mother's age, age squared, whether the child is the firstborn, and the mother's ethnic origin. Contextual controls include population density, the female employment rate, the logarithm of the provincial GDP, the provincial cohort–specific share of women with a tertiary degree, and vegetation's leaf area index. Climatic controls include relative humidity, solar radiation, wind speed, and average precipitation. Whiskers represent 95% confidence intervals.

Table 3 Comparison of results' magnitude across a selection of articles using LBW as an outcome

Study	Location	Sample	Heat (°C)	SES	Trimester	Statistic	Results P(LBW)
This Study: Table 1, Table S2 (online appendix)	50 provincial Spanish capitals	4,314,381 singletons	>32°	Parental SES assessed with ISCO, which is coded using ISEI and categorized as high, medium, and low[a]	First/second	One-day increase	↑ 0.029 PP base ↑ 0.085 PP low ↓–0.001 PP high
Chen et al. (2020: tables 2 and 7)	Rural areas in 31 Chinese provinces	637,033 singletons	>28°	Maternal education (low ≤ middle school)	Third	One-day increase	↑ 0.035 PP base ↑ 0.031 PP low ↓–0.007 PP high
Liu et al. (2022: table A6)	District in the center city of Guangzhou, China	67,108	>34.23° (top 1%)	Maternal education (low ≤ high school)	—	1% of a pregnancy (2.7 days), here transformed to one-day increase	↑ 0.15 PP base ↑ 0.19 PP low ↑ 0.037 PP high
Ngo and Horton (2016: table A1)	New York City, USA	514,104	>29.44°	—	Second	One-day increase	↑0.046 PP base (LBW by SES not studied)
Hajdu and Hajdu (2021: figure 2)	Hungary	1,532,661 singletons	>25°	Maternal education (low ≤ secondary school)	Second/third	One-day increase	Not significant, ≈ 0.01 PP (no SES differences)
Cho (2020: table 9)	South Korea	2,300,000	≥32°	—	First/second	One-day increase	Not significant, ≈ 0.036 PP highest estimate

Notes: The table summarizes the literature on the effect of heat on LBW. We select baseline estimates and, where found, also differences by SES, taking the largest estimate. We include only research with comparable temperature bins or similar estimations of the effect of heat on birth outcomes. PP = percentage points; base = baseline; low = low SES; and high = high SES.

[a] For a subsample, we also report an estimate of the effect of temperatures above 32°C on the birth outcome, with SES defined as maternal education. We define low educated as having less than a university degree, and we find an increase of 0.122 percentage points with heat experienced in the second trimester (Table S6, online appendix).

(an increase of 0.029 percentage points), and Liu et al.'s (2022) coefficients for low-educated mothers is the upper bound (an increase of 0.19 percentage points). Yet, the second-highest estimate is our coefficient on the effect of an additional day above 32°C (89.6°F) for low-SES mothers exposed in the second trimester (an increase of 0.085 percentage points). Overall, we believe our estimates are in line with comparable research.

Despite the small magnitude of one additional day of extreme heat, the estimates become substantially larger for longer spells of extreme heat. For example, five days of extreme heat relative to the reference bin during the second trimester of pregnancy would increase the risks of LBW and VLBW for low-SES offspring by approximately 0.425 and 0.115 percentage points, respectively. Compared with the sample average, these figures translate into nontrivial increases of 5% and 14% for LBW and VLBW, respectively.

Supplementary Analyses

Testing Explanations for Heterogeneous Effects

The heterogeneous effect of extreme temperatures may be explained by selective fetal deaths *in utero* (Bruckner and Catalano 2018; Hajdu and Hajdu 2021). For example, one of the SES groups may experience a disproportionate number of fetal deaths among frail fetuses when exposed to extreme heat. Consequently, a decrease in frail births for a particular SES group could erroneously suggest a heterogeneous effect on birth outcomes. We collect administrative data on late fetal deaths provided by INE from 1990 to 2016 and estimate Eq. (1) by SES, using late fetal deaths as an outcome. Figure 3 shows that heat stress increases the occurrence of late fetal deaths only for low- and medium-SES mothers in the first trimester. This result suggests that selective mortality does not drive our results. Rather, we observe an additional negative outcome among medium- and low-SES mothers, suggesting that our coefficients for the first trimester may be a conservative estimate of the effect of heat.

Another possible explanation for the heterogeneous effect of extreme temperatures is that heat waves depress fertility (Barreca et al. 2018). Fertility decisions may be stratified if high-SES parents are more aware of the risk of extreme temperatures and thus time conception to avoid hot periods and protect their newborn's health. To test this scenario, we create a province-year-month data set including the number of conceptions for each SES group and combine it with temperatures in the month the conception occurred. Figure 4 displays three regression models[4] in which the logarithm of the number of conceptions for each SES group in each province-year-month is regressed against the prior province-year-month temperature bins. We find that conceptions decrease with hot days regardless of the SES group, suggesting that selective fertility strategies do not underlie our results.

[4] Models are estimated with temperature bins defined as in Eq. (1). Models include province × year and province × month fixed effects and controls for population density, female employment rate, the logarithm of the provincial GDP per capita, the provincial cohort–specific share of women with a tertiary degree, a vegetation index, relative humidity, solar radiation, wind speed, and average precipitation.

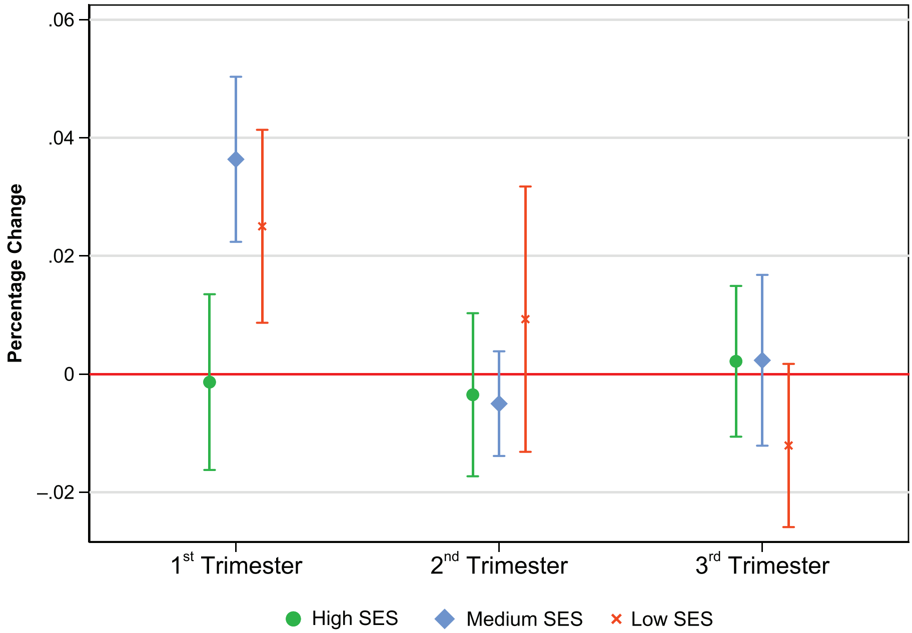

Fig. 3 Estimated effect of extreme heat (>32°C/>89.6°F) on late fetal deaths by SES and trimester. Coefficients, scaled by 100 to enhance readability, can be interpreted as percentage-point changes in late fetal deaths. Each model includes fixed effects for province × year of conception, the province-specific polynomial quadratic in the century-month of conception, and the month of conception. Demographic control variables include the mother's marital status, the mother's age, age squared, whether the child is the firstborn, and the mother's ethnic origin. Contextual controls include population density, the female employment rate, the logarithm of the provincial GDP, the provincial cohort–specific share of women with a tertiary degree, and vegetation's leaf area index. Climatic controls include relative humidity, solar radiation, wind speed, and average precipitation. Whiskers represent 95% confidence intervals.

Finally, we explore whether disparities in exposure may be a possible explanation for the heterogeneous effects of extreme temperature. We use OECD data to compare the proportion of households with access to air conditioning by SES group.[5] We find a gradient in air conditioning access among Spanish households, with 55% of high-SES individuals having access to air conditioning at home, compared with only 38% for low-SES individuals. This result suggests that advantaged mothers may be more likely to access air conditioning to shelter their offspring from intense heat stress.

Sensitivity Analyses and Robustness Checks

We perform our analyses again, this time using different indicators of temperature and heat. First, we replicate our analyses using a heat index that combines temperature

[5] Data are drawn from the OECD's 2011 Environmental Policy and Individual Behaviour Change survey. Information on the data set is available at https://www.oecd.org/environment/households.htm.

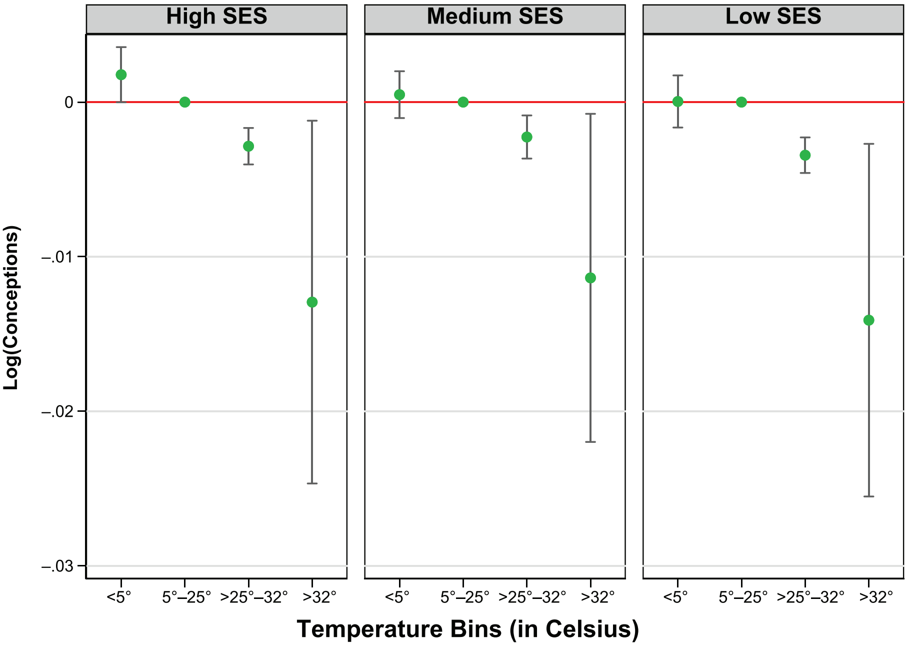

Fig. 4 Estimated effect of temperatures on the number of conceptions (logged). Temperature bins are cold days (<5°C/<41°F), days in the comfort zone (5°C–25°C/41°F–77°F), warm days (>25°C–32°C/>77°F–89.6°F), and hot days (>32°C/>89.6°F). Estimates are obtained by generating a province-year-month-SES data set with the number of conceptions for each cell and the number of days within a certain temperature bin. Models include province × year and province × month fixed effects. Contextual controls include population density, the female employment rate, the logarithm of the provincial GDP, the provincial cohort–specific share of women with a tertiary degree, and vegetation's leaf area index. Climatic controls include relative humidity, solar radiation, wind speed, and average precipitation. Whiskers represent 95% confidence intervals.

with humidity to compute a more accurate estimate of perceived temperature (for more information on this index, see Opitz-Stapleton et al. 2016). These results are fully consistent with an effect of heat on LBW concentrated among low-SES offspring (Table S3, online appendix). Second, we redefine temperature bins as <0°C, 0°C–5°C, >5°C–20°C (the reference bin), >20°C–25°C, >25°C–30°C, and >30°C.[6] Consistent with results presented earlier, we find that an additional day above 30°C (86°F) increases the risk of LBW only for low-SES offspring (Table S4, online appendix). The effect size for an additional day above 30°C is smaller than that for an additional day above 32°C (89.6°F), likely due to the lower heat threshold. Third, we test whether the inability to cool off at night (the so-called tropical nights) has a detrimental effect on birth outcomes. We define a tropical night as a day with a minimum temperature above 20°C (68°F) (Cantos et al. 2019). Our results do not show any effect of tropical nights on birth outcomes (Table S5, online appendix).

[6] These categories, respectively, are <32°F, 32°F–41°F, >41°F–68°F (reference bin), >68°F–77°F, >77°F–86°F, and >86°F.

Most studies on the heterogeneous effect of extreme heat on birth outcomes have used maternal education as the SES indicator (as summarized in Table 3). We replicate our analyses for the subgroup of newborns (2007–2016) for which we have available information on mothers' educational levels, distinguishing between mothers who have a university degree and those who do not. For the outcome of LBW, the results are consistent with an effect of heat exposure in the second trimester of pregnancy for mothers having less than a university degree ($\beta = 0.122$; $p < .05$). We also replicate the analyses in the same period (2007–2016) with our classification of SES based on occupational status. These results are fully consistent with those using educational indicators (Table S6, online appendix).

In addition, our main estimates are robust to a range of fixed-effects specifications (see Table S7 in the online appendix). For both LBW and VLBW, the effect of heat among low-SES offspring is unchanged by alternative combinations of fixed effects in the province, month of conception, year of conception, and the quadratic polynomial in the century-month of conception.

Following common practice in the literature, we conduct a placebo test using exposure to temperature bins in the 9 months before conception by SES, as in Table 2 (see Table S8, online appendix). The analyses show no detrimental effect of heat, lending support to our results. Because some autocorrelation in assigning lagged placebo temperatures within the same provincial capital may produce significant effects, we compare the effect of exposure to temperatures beyond 32°C (89.6°F) from Table 2 with placebo estimates in Table S8 (online appendix). All the coefficients in Table 2 for low-SES offspring are statistically different ($p < .05$) from placebo estimates.

Discussion and Conclusion

This article investigates the effect of extreme heat on birth outcomes and whether the effect is heterogeneous among socioeconomic strata. We found two main results. First, we observed a negative effect of exposure to temperatures above 32°C (89.6°F) on birth outcomes, such as LBW and VLBW, particularly when extreme temperatures occurred in early pregnancy. We found no substantial effect on the probability of PTB, suggesting that heat may influence fetal growth rather than prematurity. Moreover, we also found evidence suggesting that male fetuses may be more susceptible to insults *in utero*, in line with prior studies (Currie and Schwandt 2016; DiPietro and Voegtline 2017).

The second and most relevant finding is that SES matters for the possible consequences of hot temperatures on birth outcomes. On the one hand, we find that low-SES mothers are more likely to deliver infants with poor birth outcomes after exposure to hot temperatures *in utero*. Although we could not extensively test mechanisms, our ancillary analyses suggest that this pattern is not accounted for by selective mortality *in utero* or planned fertility. The gradient in access to air conditioning provides evidence suggesting that parental resources provide shelter from extreme temperatures. Low-SES mothers might experience higher levels of material deprivation and lack the resources to adapt to environmental stressors. Additionally, they might live in poorer areas of a city without the refreshing effects of green spaces and reside in buildings without proper insulation from outside weather conditions. On the other hand, some high-SES mothers who are exposed to extreme heat during pregnancy seem to reduce the risk of delivering children with poorer birth outcomes. A possible interpretation of this finding is that high-SES parents may try to compensate for the exposure to extreme heat (Bernardi 2014; Torche 2018). For example, the availability of air conditioning, the possibility of vacationing in an area with milder weather, and the extra care taken during hot days could be mechanisms for this effect.

Regarding other studies on urban populations, our results showing a detrimental effect of extreme temperatures on birth outcomes only among low-SES mothers are in line with studies in Guangzhou (China) and New York City (Liu et al. 2022; Ngo and Horton 2016). However, our results contrast with research finding that highly educated mothers in California were the most vulnerable to extreme heat (Basu et al. 2018) and with research from Hungary demonstrating no meaningful differences across SES groups (Hajdu and Hajdu 2021). Because these studies measured the impact of heat using temperature bins and alternate assessments and investigated different contexts as case studies, methodological and country differences do not explain these mixed results.

Our study is not free of caveats. First, our focus on an urban population calls for caution in generalizing the results to rural areas. Second, data limitations prevented us from testing whether preexisting health conditions account for our finding of an SES gradient. Third, one possible source of bias in our study is the influence of air pollution (Chersich et al. 2020), which might affect both maternal health and the fetus (Slama et al. 2008). Unfortunately, data on air pollution for most European countries are available only beginning with the early 2000s, which largely does not overlap with our observation period of 1990–2016.[7] Nevertheless, previous studies that controlled for air pollution found a persistent negative effect of temperature on birth outcomes (Ngo and Horton 2016). Finally, our use of temperature bins assumes a linear effect of each day in a temperature bin on birth outcomes. In reality, there may be some nonlinearities or threshold effects.

Future research should focus on four main gaps we did not tackle in this article. First, we focused on differences among socioeconomic groups, but inequality may also change across time. Future research should investigate whether the availability of more affordable electricity and air conditioning technologies might have reduced the risks associated with heat stress in the later cohorts, as found in one study in Australia (Li et al. 2018) or in studies on heat-related mortality (Achebak et al. 2019; Barreca et al. 2016). Second, it is important to investigate the mechanisms explaining heterogeneities between SES groups and the prevalence of negative outcomes among low-SES mothers. Third, as mentioned earlier, research should further investigate SES heterogeneities in the consequences of extreme heat to explain the conflicting results in the literature. Fourth, it may be valuable to directly assess whether there are nonlinearities or threshold effects of temperature on birth outcomes.

[7] For example, the Spanish Ministry of Ecological Change provided data on air pollution gathered by stations located in the major cities, but only since 2001. Moreover, the data set has several missing values, preventing us from analyzing the entire sample of provincial capitals. Consequently, introducing this variable in our analysis considerably and nonrandomly shrinks the total sample, making it incomparable with the sample in our main analysis.

In conclusion, this article offers at least two important lessons on the negative effect of heat stress on birth outcomes that inform policy making. First, disadvantaged pregnant women waiting for a male newborn may be particularly susceptible to climate conditions, and they should be advised against this risk. Second, given the importance of birth outcomes for the well-being of the next generation, the SES gradient in the effect of heat stress raises concerns about the possible climate change–driven increase in socioeconomic inequalities in future decades. ■

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References

Abel, T. (2008). Cultural capital and social inequality in health. *Journal of Epidemiology and Community Health, 62,* e13. http://dx.doi.org/10.1136/jech.2007.066159

Achebak, H., Devolder, D., & Ballester, J. (2019). Trends in temperature-related age-specific and sex-specific mortality from cardiovascular diseases in Spain: A national time-series analysis. *Lancet Planetary Health, 3,* e297–e306. https://doi.org/10.1016/S2542-5196(19)30090-7

Almond, D., & Currie, J. (2011). Killing me softly: The fetal origins hypothesis. *Journal of Economic Perspectives, 25*(3), 153–172.

Almond, D., Currie, J., & Duque, V. (2018). Childhood circumstances and adult outcomes: Act II. *Journal of Economic Literature, 56,* 1360–1446.

Almond, D., & Mazumder, B. (2013). Fetal origins and parental responses. *Annual Review of Economics, 5,* 37–56.

Aquino, T., Brand, J. E., & Torche, F. (2022). Unequal effects of disruptive events. *Sociology Compass, 16,* e12972. https://doi.org/10.1111/soc4.12972

Barker, D. J. P. (1990). The fetal and infant origins of adult disease. *BMJ, 301,* 1111.

Baron, R., Manniën, J., te Velde, S. J., Klomp, T., Hutton, E. K., & Brug, J. (2015). Socio-demographic inequalities across a range of health status indicators and health behaviours among pregnant women in prenatal primary care: A cross-sectional study. *BMC Pregnancy and Childbirth, 15,* 261. https://doi.org/10.1186/s12884-015-0676-z

Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to climate change: The remarkable decline in the U.S. temperature-mortality relationship over the twentieth century. *Journal of Political Economy, 124,* 105–159.

Barreca, A., Deschenes, O., & Guldi, M. (2018). Maybe next month? Temperature shocks and dynamic adjustments in birth rates. *Demography, 55,* 1269–1293.

Basto-Abreu, A., Barrientos-Gutiérrez, T., Zepeda-Tello, R., Camacho, V., Gimeno Ruiz de Porras, D., & Hernández-Ávila, M. (2018). The relationship of socioeconomic status with body mass index depends on the socioeconomic measure used. *Obesity, 26,* 176–184.

Basu, R., Rau, R., Pearson, D., & Malig, B. (2018). Temperature and term low birth weight in California. *American Journal of Epidemiology, 187,* 2306–2314.

Bekkar, B., Pacheco, S., Basu, R., & DeNicola, N. (2020). Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the U.S.: A systematic review. *JAMA Network Open, 3,* e208243. https://doi.org/10.1001/jamanetworkopen.2020.8243

Bell, A. W., Wilkening, R. B., & Meschia, G. (1987). Some aspects of placental function in chronically heat-stressed ewes. *Journal of Developmental Physiology, 9*(1), 17–29.

Beniston, M., Stephenson, D. B., Christensen, O. B., Ferro, C. A., Frei, C., Goyette, S., . . . Koffi, B. (2007). Future extreme events in European climate: An exploration of regional climate model projections. *Climatic Change, 81,* 71–95.

Bernardi, F. (2014). Compensatory advantage as a mechanism of educational inequality: A regression discontinuity based on month of birth. *Sociology of Education, 87,* 74–88.

Bernardi, F., Chakhaia, L., & Leopold, L. (2017). "Sing me a song with social significance": The (mis)use of statistical significance testing in European sociological research. *European Sociological Review, 33,* 1–15.

Black, S. E., Devereux, P. J., & Salvanes, K. G. (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. *Quarterly Journal of Economics, 122,* 409–439.

Boardman, J. D., Powers, D. A., Padilla, Y. C., & Hummer, R. A. (2002). Low birth weight, social factors, and developmental outcomes among children in the United States. *Demography, 39,* 353–368.

Brown, R. (2018). The Mexican drug war and early-life health: The impact of violent crime on birth outcomes. *Demography, 55,* 319–340.

Brown, R. (2020). The intergenerational impact of terror: Did the 9/11 tragedy impact the initial human capital of the next generation? *Demography, 57,* 1459–1481.

Bruckner, T. A., & Catalano, R. (2018). Selection in utero and population health: Theory and typology of research. *SSM–Population Health, 5,* 101–113. https://doi.org/10.1016/j.ssmph.2018.05.010

Cantos, J. O., Serrano-Notivoli, R., Miró, J., & Meseguer-Ruiz, O. (2019). Tropical nights on the Spanish Mediterranean coast, 1950–2014. *Climate Research, 78,* 225–236.

Chen, X., Tan, C. M., Zhang, X., & Zhang, X. (2020). The effects of prenatal exposure to temperature extremes on birth outcomes: The case of China. *Journal of Population Economics, 33,* 1263–1302.

Chersich, M. F., Pham, M. D., Areal, A., Haghighi, M. M., Manyuchi, A., Swift, C. P., . . . Boeckmann, M. (2020). Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: Systematic review and meta-analysis. *BMJ, 371,* m3811. https://doi.org/10.1136/bmj.m3811

Chirakijja, J., Jayachandran, S., & Ong, P. (2019). *Inexpensive heating reduces winter mortality* (NBER Working Paper 25681). Cambridge, MA: National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w25681

Cho, H. (2020). Ambient temperature, birth rate, and birth outcomes: Evidence from South Korea. *Population and Environment, 41,* 330–346.

Clogg, C. C., Petkova, E., & Haritou, A. (1995). Statistical methods for comparing regression coefficients between models. *American Journal of Sociology, 100,* 1261–1293.

Conley, D. (2008). Bringing sibling differences in: Enlarging our understanding of the transmission of advantage in families. In A. Lareau & D. Conley (Eds.), *Social class: How does it work?* (pp. 179–200). New York, NY: Russell Sage Foundation.

Cornes, R. C., van der Schrier, G., van den Besselaar, E. J., & Jones, P. D. (2018). An ensemble version of the E-OBS temperature and precipitation data sets. *Journal of Geophysical Research: Atmospheres, 123,* 9391–9409.

Cozzani, M., Triventi, M., & Bernardi, F. (2022). Maternal stress and pregnancy outcomes. Evidence from a natural experiment: The 2004 Madrid train bombings. *European Sociological Review, 38,* 390–407.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., . . . Paz, S. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change, 8,* 972–980.

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

Currie, J., & Schwandt, H. (2016). The 9/11 dust cloud and pregnancy outcomes: A reconsideration. *Journal of Human Resources, 51,* 805–831.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature, 52,* 740–798.

de Oliveira, V. H., Lee, I., & Quintana-Domeque, C. (2021). Natural disasters and early human development: Hurricane Catarina and infant health in Brazil. *Journal of Human Resources*. Advance online publication. https://doi.org/10.3368/jhr.59.1.0816-8144R1

Deschênes, O., Greenstone, M., & Guryan, J. (2009). Climate change and birth weight. *American Economic Review: Papers & Proceedings, 99,* 211–217.

DiPietro, J. A., & Voegtline, K. M. (2017). The gestational foundation of sex differences in development and vulnerability. *Neuroscience, 342,* 4–20.

Duncan, B., Mansour, H., & Rees, D. I. (2017). It's just a game: The Super Bowl and low birth weight. *Journal of Human Resources, 52,* 946–978.

Duong, H. T., Shahrukh Hashmi, S., Ramadhani, T., Canfield, M. A., Scheuerle, A., Kim Waller, D., & National Birth Defects Prevention Study. (2011). Maternal use of hot tub and major structural birth defects. *Birth Defects Research Part A: Clinical and Molecular Teratology, 91,* 836–841.

Edwards, M. J. (1998). Apoptosis, the heat shock response, hyperthermia, birth defects, disease and cancer. Where are the common links? *Cell Stress & Chaperones, 3,* 213–220.

Fischer, E. M., Oleson, K. W., & Lawrence, D. M. (2012). Contrasting urban and rural heat stress responses to climate change. *Geophysical Research Letters, 39,* L03705. https://doi.org/10.1029/2011GL050576

Forastiere, F., Stafoggia, M., Tasco, C., Picciotto, S., Agabiti, N., Cesaroni, G., & Perucci, C. A. (2007). Socioeconomic status, particulate air pollution, and daily mortality: Differential exposure or differential susceptibility. *American Journal of Industrial Medicine, 50,* 208–216.

Fukuda, M., Fukuda, K., Shimizu, T., Nobunaga, M., Mamsen, L. S., & Andersen, C. Y. (2014). Climate change is associated with male:female ratios of fetal deaths and newborn infants in Japan. *Fertility and Sterility, 102,* 1364–1370.e2. https://doi.org/10.1016/j.fertnstert.2014.07.1213

Ganzeboom, H. B., & Treiman, D. J. (1996). Internationally comparable measures of occupational status for the 1988 International Standard Classification of Occupations. *Social Science Research, 25,* 201–239.

Graham, J. M. (2005). Marshall J. Edwards: Discoverer of maternal hyperthermia as a human teratogen. *Birth Defects Research Part A: Clinical and Molecular Teratology, 73,* 857–864.

Hajdu, T., & Hajdu, G. (2021). Temperature, climate change, and birth weight: Evidence from Hungary. *Population and Environment, 43,* 131–148.

Härkönen, J., Kaymakçalan, H., Mäki, P., & Taanila, A. (2012). Prenatal health, educational attainment, and intergenerational inequality: The Northern Finland Birth Cohort 1966 Study. *Demography, 49,* 525–552.

Hovdahl, I. (2020). *Deadly variation: The effect of temperature variability on mortality* (CAMP Working Paper Series, No. 01/2020). Oslo, Norway: Centre for Applied Macroeconomics and Commodity Prices, BI Norwegian Business School.

Isen, A., Rossin-Slater, M., & Walker, R. (2017). Relationship between season of birth, temperature exposure, and later life wellbeing. *Proceedings of the National Academy of Sciences, 114,* 13447–13452.

Juárez, S., Alonso Ortíz, T., Ramiro-Fariñas, D., & Bolúmar, F. (2012). The quality of vital statistics for studying perinatal health: The Spanish case. *Paediatric and Perinatal Epidemiology, 26,* 310–315.

Kawachi, I., Kennedy, B. P., Lochner, K., & Prothrow-Stith, D. (1997). Social capital, income inequality, and mortality. *American Journal of Public Health, 87,* 1491–1498.

Kovats, R. S., & Hajat, S. (2008). Heat stress and public health: A critical review. *Annual Review of Public Health, 29,* 41–55.

Laburn, H. P. (1996). How does the fetus cope with thermal challenges? *Physiology, 11,* 96–100.

Le, K., & Nguyen, M. (2021). The impacts of temperature shocks on birth weight in Vietnam. *Population and Development Review, 47,* 1025–1047.

Li, S., Chen, G., Jaakkola, J. J. K., Williams, G., & Guo, Y. (2018). Temporal change in the impacts of ambient temperature on preterm birth and stillbirth: Brisbane, 1994–2013. *Science of the Total Environment, 634,* 579–585.

Lionello, P., Malanotte-Rizzoli, P., Boscolo, R., Alpert, P., Artale, V., Li, L., . . . Xoplaki, E. (2006). The Mediterranean climate: An overview of the main characteristics and issues. In P. Lionello, P. Malanotte-Rizzoli, & R. Boscolo (Eds.), *Developments in earth and environmental sciences: Vol. 4. Mediterranean climate variability* (pp. 1–26). Amsterdam, the Netherlands: Elsevier.

Liu, X., Behrman, J., Hannum, E., Wang, F., & Zhao, Q. (2022). Same environment, stratified impacts? Air pollution, extreme temperatures, and birth weight in South China. *Social Science Research, 105,* 102691. https://doi.org/10.1016/j.ssresearch.2021.102691

Mackenbach, J. P., Stirbu, I., Roskam, A. J. R., Schaap, M. M., Menvielle, G., Leinsalu, M., & Kunst, A. E. (2008). Socioeconomic inequalities in health in 22 European countries. *New England Journal of Medicine, 358,* 2468–2481.

McCloskey, D. N., & Ziliak, S. T. (1996). The standard error of regressions. *Journal of Economic Literature, 34,* 97–114.

Milunsky, A., Ulcickas, M., Rothman, K. J., Willett, W., Jick, S. S., & Jick, H. (1992). Maternal heat exposure and neural tube defects. *JAMA, 268,* 882–885.

Ngo, N. S., & Horton, R. M. (2016). Climate change and fetal health: The impacts of exposure to extreme temperatures in New York City. *Environmental Research, 144,* 158–164.

Opitz-Stapleton, S., Sabbag, L., Hawley, K., Tran, P., Hoang, L., & Nguyen, P. H. (2016). Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam. *Climate Services, 2–3,* 41–51.

Palloni, A. (2006). Reproducing inequalities: Luck, wallets, and the enduring effects of childhood health. *Demography, 43,* 587–615.

Pampel, F. C., Krueger, P. M., & Denney, J. T. (2010). Socioeconomic disparities in health behaviors. *Annual Review of Sociology, 36,* 349–370.

Perkins-Kirkpatrick, S., & Lewis, S. (2020). Increasing trends in regional heatwaves. *Nature Communications, 11,* 3357. https://doi.org/10.1038/s41467-020-16970-7

Persson, P., & Rossin-Slater, M. (2018). Family ruptures, stress, and the mental health of the next generation. *American Economic Review, 108,* 1214–1252.

Polin, R. A., Fox, W. W., & Abman, S. H. (Eds.). (2011). *Fetal and neonatal physiology* (4th ed., E-book). Philadelphia, PA: Elsevier Saunders.

Ravanelli, N., Casasola, W., English, T., Edwards, K. M., & Jay, O. (2019). Heat stress and fetal risk. Environmental limits for exercise and passive heat stress during pregnancy: A systematic review with best evidence synthesis. *British Journal of Sports Medicine, 53,* 799–805.

Regnault, T. R. H., Friedman, J. E., Wilkening, R. B., Anthony, R. V., & Hay, W. W., Jr. (2005). Fetoplacental transport and utilization of amino acids in IUGR—A review. *Placenta, 26*(Suppl.), S52–S62.

Schultz, W. M., Kelli, H. M., Lisko, J. C., Varghese, T., Shen, J., Sandesara, P., . . . Harold, J. G. (2018). Socioeconomic status and cardiovascular outcomes: Challenges and interventions. *Circulation, 137,* 2166–2178.

Slama, R., Darrow, L., Parker, J., Woodruff, T. J., Strickland, M., Nieuwenhuijsen, M., . . . Hurley, F. (2008). Meeting report: Atmospheric pollution and human reproduction. *Environmental Health Perspectives, 116,* 791–798.

Son, J.-Y., Lee, J.-T., Lane, K. J., & Bell, M. L. (2019). Impacts of high temperature on adverse birth outcomes in Seoul, Korea: Disparities by individual- and community-level characteristics. *Environmental Research, 168,* 460–466.

Stott, P. A., Stone, D. A., & Allen, M. R. (2004). Human contribution to the European heatwave of 2003. *Nature, 432,* 610–614.

Taylor, E. V., Vaidyanathan, A., Flanders, W. D., Murphy, M., Spencer, M., & Noe, R. S. (2018). Differences in heat-related mortality by citizenship status: United States, 2005–2014. *American Journal of Public Health, 108*(S2), S131–S136.

Torche, F. (2018). Prenatal exposure to an acute stressor and children's cognitive outcomes. *Demography, 55,* 1611–1639.

Torche, F., & Conley, D. (2016). A pound of flesh: The use of birthweight as a measure of human capital endowment in economics research. In J. Komlos & I. R. Kelly (Eds.), *The Oxford handbook of economics and human biology* (pp. 632–649). New York, NY: Oxford University Press.

Torche, F., & Villarreal, A. (2014). Prenatal exposure to violence and birth weight in Mexico: Selectivity, exposure, and behavioral responses. *American Sociological Review, 79,* 966–992.

Varghese, B. M., Hansen, A., Bi, P., & Pisaniello, D. (2018). Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. *Safety Science, 110*(Part A), 380–392.

Wells, J. C. (2002). Thermal environment and human birth weight. *Journal of Theoretical Biology, 214,* 413–425.

Wilde, J., Apouey, B. H., & Jung, T. (2017). The effect of ambient temperature shocks during conception and early pregnancy on later life outcomes. *European Economic Review, 97,* 87–107.

Zhang, Y., Yu, C., & Wang, L. (2017). Temperature exposure during pregnancy and birth outcomes: An updated systematic review of epidemiological evidence. *Environmental Pollution, 225,* 700–712.

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