

# “Heatwaves and Health at Birth”

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## Abstract

This paper studies the impact of prenatal exposure to extreme heat on birth outcomes in Spain. I link over 460,000 administrative birth records from 2012–2021 to high-resolution daily temperature data at the municipality level to construct trimester-specific measures of in-utero heat exposure. Heatwaves are defined as at least three consecutive days with maximum temperatures above the municipality-specific 95th percentile of the historical distribution, with alternative thresholds used for robustness. In contrast to most of the existing literature, I find that exposure to heatwaves during pregnancy—particularly in the third trimester—increases birth weight and gestational age, and modestly raises the probability of cesarean delivery. These results are robust across alternative definitions of extreme heat, model specifications, and functional forms. The findings suggest that in the Spanish context, moderate heat exposure may stimulate fetal growth through behavioral or medical adaptations, highlighting the importance of understanding local resilience and adaptation in the face of a warming climate.

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# 1 Introduction

Climate change is increasing the frequency, intensity, and duration of extreme heat events, raising urgent concerns for public health. Heatwaves are particularly worrying for vulnerable populations such as the elderly, outdoor workers, and pregnant women. Fetal development is a critical stage for long-term health and human capital formation (Currie and Rossin-Slater, 2013), and temperature shocks during gestation are often believed to have lasting adverse effects.

A large literature documents that prenatal exposure to heat impairs fetal growth and shortens gestation. Heat stress may lead to dehydration, impaired placental function, or premature labor (Wyrwoll, 2023). Consistent with these mechanisms, Chersich et al. (2020) report strong global associations between high ambient temperatures and low birth weight, preterm birth, and stillbirth. Wang et al. (2013) find that exposure to heatwaves in late pregnancy increases preterm birth risk in Brisbane, while Sun et al. (2020) show that heat, when combined with pollution and limited green space, raises preterm delivery rates in California.

Despite this broad evidence, little is known about how heat exposure affects birth outcomes in Southern Europe—a region projected to experience some of the sharpest increases in heatwave intensity (IPCC, 2023). Moreover, existing studies mostly document adverse effects, leaving open whether and why these patterns might differ across climatic, social, or institutional contexts. Spain provides an especially valuable case to investigate this question. The country combines substantial spatial and temporal variation in temperature with universal access to prenatal and delivery care, offering an environment where the biological effects of heat can be studied with minimal confounding from healthcare access or income disparities (Keivabu and Cozzani, 2022).

This paper examines how in-utero exposure to extreme heat affects neonatal outcomes in Spain. I link individual-level birth records from the Spanish Vital Statistics to high-resolution daily temperature data at the municipality level for 2012–2021. Using this merged dataset, I construct trimester-specific measures of exposure to hot days and heatwaves, defined in percentile-based thresholds. Contrary to the prevailing evidence, I find that exposure to heatwaves during pregnancy increases birth weight and gestational age. These effects are concentrated in the third trimester and are robust across multiple definitions of heat exposure, model specifications. The results suggest that, in the Spanish context, short-term heat stress may accelerate delivery only when extreme and sustained, while moderate exposure may act through physiological or behavioural adaptations that favour fetal growth.

A key question raised by these results is why moderate heat exposure appears beneficial

rather than harmful. Several mechanisms may help explain this pattern. From a physiological perspective, mild heat stress can increase maternal blood flow and metabolic activity, potentially enhancing nutrient delivery to the fetus. At the behavioural level, heatwaves may prompt pregnant women to reduce physical activity, increase hydration, or spend more time resting indoors, behaviours that could support fetal growth. Institutional factors may also play a role: during periods of extreme heat, prenatal monitoring and medical vigilance may intensify, and air conditioning use may help offset the adverse physiological effects of heat. Later sections of the paper examine these potential pathways by exploring heterogeneity in effects across socioeconomic groups, urban environments, and newborn characteristics.

## 1.1 Contribution

This paper contributes to several strands of the literature.

First, it adds new evidence to the growing body of research on the effects of temperature on health and human capital. While most studies document negative impacts of prenatal heat exposure on birth outcomes, my findings reveal the opposite pattern in a Southern European setting. This challenges the conventional narrative that extreme heat uniformly harms fetal development and suggests that contextual factors—such as adaptation, healthcare access, and climate norms—play a critical role.

Second, the paper contributes to the literature on climate adaptation and health. By documenting a setting where the short-term consequences of heat exposure appear non-adverse, it highlights the potential importance of behavioral and institutional responses—such as hydration, rest, or air conditioning—in mitigating physiological stress. Understanding these mechanisms can inform adaptation strategies in regions facing increasing climate variability.

Finally, this work contributes methodologically by combining administrative birth micro-data with high-frequency meteorological information to construct precise, trimester-level measures of in-utero heat exposure. This fine temporal matching allows me to isolate gestational periods most sensitive to temperature shocks, advancing empirical approaches to studying climate–health interactions.

## 2 Related Literature

Research across economics, epidemiology, and environmental health has increasingly documented that prenatal exposure to extreme temperatures can affect fetal development

and neonatal outcomes. A broad consensus links high ambient temperatures to higher risks of low birth weight, preterm delivery, and stillbirth (Chersich et al., 2020; Wang et al., 2013; Chen et al., 2020; Richards et al., 2022). The proposed mechanisms include dehydration, impaired placental function, and inflammation during maternal heat stress (Wyrwoll, 2023). These effects are consistent with a growing body of evidence showing that heat can act as a physiological stressor that disrupts gestation and accelerates delivery.

Recent work highlights that the interaction of heat with other environmental stressors may amplify health risks. Sun et al. (2020) and Ha et al. (2024) find that concurrent exposure to high temperatures, air pollution, and wildfire smoke significantly raises the likelihood of preterm birth in California. These findings point to the importance of studying compound exposures and to potential synergies between environmental shocks. At the same time, social and economic factors shape both exposure and vulnerability: Cushing et al. (2022) show that low-income and racially marginalized mothers face disproportionate heat-related risks, underscoring the role of adaptation capacity and structural inequality.

Beyond physiology and exposure, institutional and behavioral mechanisms also appear relevant. For instance, Costa-Ramón et al. (2018) show that physician incentives affect cesarean section timing in Spain, while Costa-Ramón et al. (2022) link cesarean delivery to adverse long-term child outcomes. These findings suggest that obstetric practices can mediate the relationship between environmental stress and newborn health. Similarly, Currie and Rossin-Slater (2013) and Quintana-Domeque and Ródenas-Serrano (2017) provide evidence that maternal stress from natural disasters or violence reduces birth weight, supporting the broader notion that environmental shocks influence pregnancy through both physiological and behavioral pathways.

Most of the empirical evidence on heat and birth outcomes comes from the United States, China, and Australia, with relatively little work on Southern Europe. This gap is relevant because the region is projected to experience some of the world's most severe increases in heatwave frequency and intensity (IPCC, 2023). In Spain, Díaz et al. (2018) and Roldán et al. (2016) document rising heat-related mortality and health burdens, while Keivabu and Cozzani (2022) show that high temperatures reduce fertility, particularly in regions with limited access to cooling. However, no study has yet examined how in-utero heat exposure affects birth outcomes using nationally representative administrative microdata.

This paper contributes to filling this gap by providing the first large-scale evidence for Spain on the relationship between gestational heat exposure and newborn health. Unlike most existing work, which finds detrimental effects, I find that heat exposure during pregnancy—especially in the third trimester—increases birth weight and gestational length. This contrast with prior findings opens new questions about adaptation, behavior, and

the role of local climate and health systems in shaping the consequences of extreme heat.

## 3 Data

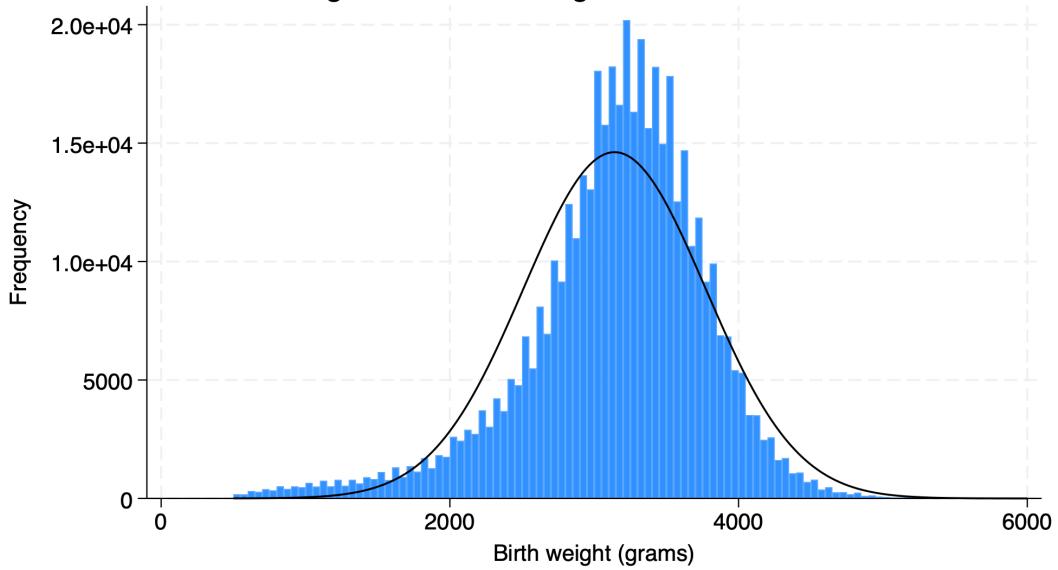
### 3.1 Overview

This paper combines rich administrative microdata on births with high-resolution meteorological information to examine how exposure to extreme heat during gestation affects health at birth in Spain. The analysis draws on detailed records from the Spanish Vital Statistics (Estadística de Nacimientos), which provide exhaustive information on all live births and stillbirths, and links them to municipality-level daily temperature data from the E-OBS climate reanalysis dataset. The merged dataset integrates demographic, clinical, and meteorological dimensions at a fine temporal and spatial scale, allowing me to identify exposure to hot days and heatwaves for each pregnancy and estimate their effects on multiple birth outcomes.

### 3.2 Dependent Variables

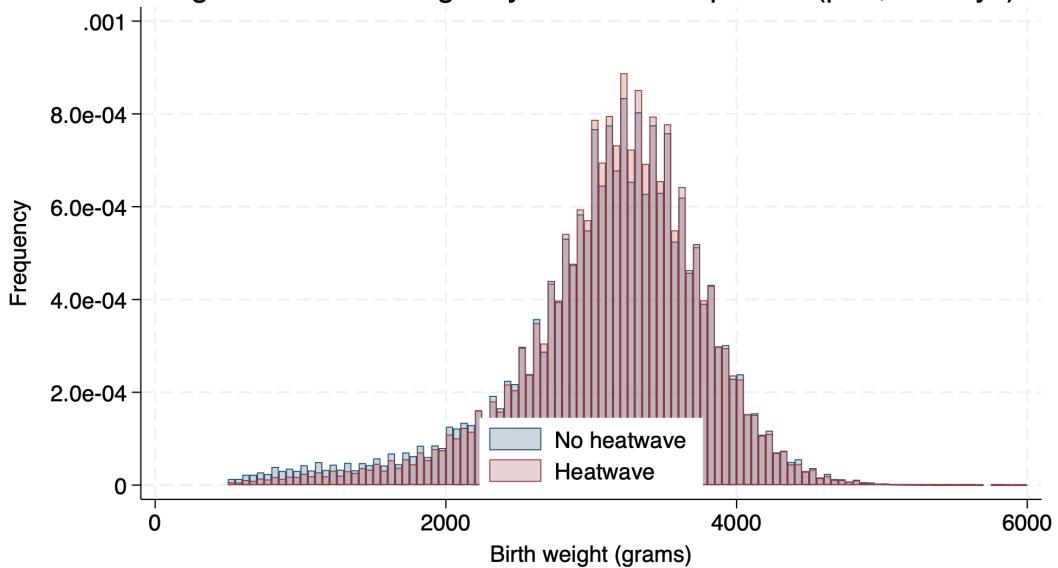
The main outcome variable is birth weight (PESON), measured in grams and available for every newborn. I complement this with two additional indicators that capture other dimensions of neonatal health: gestational age at delivery (SEMANAS), expressed in completed weeks of gestation, and a binary indicator for cesarean delivery (CESAREA), distinguishing between vaginal and cesarean births. These outcomes are standard in the health economics and epidemiological literature and enable a multidimensional assessment of how maternal exposure to heat during pregnancy affects both fetal growth and obstetric complications.

**Figure 2a. Birth weight: overall distribution**



(a) Birth weight: overall distribution

**Figure 2b. Birth weight by heatwave exposure (p95,  $\geq 3$  days)**



(b) Birth weight by heatwave exposure (p95,  $\geq 3$  days)

Figure 1: Distribution of birth weight and comparison by heatwave exposure

Notes: Panel (a) shows the overall distribution of birth weight for the full sample of births between 2012 and 2021. Panel (b) compares the birth weight distribution for pregnancies exposed and unexposed to a heatwave ( $\geq 3$  consecutive days above the municipality-specific 95th percentile of Tmax).

Figure 1 illustrates the distribution of birth weight in the sample. Panel (a) shows

that birth weight is approximately normal, centered around 3,250 grams, with a slight right tail. Panel (b) compares distributions for pregnancies exposed and unexposed to heatwaves. The two curves overlap closely but show a modest rightward shift for exposed births, consistent with the regression results that heatwave exposure, particularly late in gestation, increases average birth weight.

### 3.3 Main Independent Variable: Heat Exposure

To measure exposure to extreme temperatures during gestation, I link each individual birth record to a daily series of maximum temperatures ( $T_{max}$ ) corresponding to the mother's municipality of residence (`cod_ine`) throughout the entire gestational period. This linkage produces a day-level panel in which each row represents one day of gestation for a specific pregnancy. From this expanded dataset, I compute detailed indicators of heat exposure—such as the number of hot days and the occurrence of heatwaves—based on both absolute and percentile thresholds calculated from local temperature distributions. These measures are then aggregated to the pregnancy level, resulting in one observation per birth that combines demographic and clinical characteristics with comprehensive indicators of temperature exposure. The final dataset covers all births in Spain between 2012 and 2021. To link daily temperature data to each pregnancy, I constructed a unique identification code that distinguishes individual births based on a combination of observable maternal and birth characteristics. This identifier allowed me to expand the dataset to the day level and then collapse it back to the pregnancy level while preserving one-to-one correspondence between records. In a number of cases, identical identifiers were generated for distinct records with the same observable characteristics. In such instances, I retained one randomly selected record to avoid duplication. This procedure ensured internal consistency of the dataset and preserves a representative sample of births for the analysis.

### 3.4 Sample Construction and Representativeness

I construct a unique birth identifier using [mother's age, parity, marital status, municipality, month–year of birth, sex] and keep the first non-missing record when duplicates arise. This yields  $\sim 460,000$  births for 2012–2021. I link births to municipality-level daily  $T_{max}$  from E-OBS using the mother's municipality of residence, aggregate to gestational day, and collapse to trimester-specific exposure measures. Observations with missing municipality codes or implausible gestational ages are dropped.

### 3.5 Controls and Mechanisms

The birth records include a rich set of maternal and child characteristics that I use both as controls and as potential mechanisms. Control variables include maternal age, education level, and parity (number of previous children), which capture socioeconomic and demographic factors correlated with both fertility and health outcomes. I also control for the sex of the newborn, given evidence that male fetuses are generally more vulnerable to environmental stressors.

To explore mechanisms beyond average birth outcomes, I use indicators of adverse perinatal events. Specifically, the data record whether the infant was born alive (NACVN) and whether the newborn died before or during delivery (MUERN). These outcomes allow me to assess whether extreme heat affects not only fetal growth and gestational duration but also perinatal survival, offering insight into the physiological and behavioral channels through which maternal heat exposure may influence reproductive health.

Appendix Table A1 compares observable maternal characteristics and birth outcomes between pregnancies with and without heatwave exposure. Differences are small in magnitude, confirming that exposed and unexposed groups are broadly comparable along socioeconomic and demographic dimensions.

## 4 Empirical Strategy

The objective of this paper is to estimate the causal impact of prenatal exposure to extreme heat on health at birth. The main empirical challenge arises because temperature varies systematically with other seasonal or local factors that may also influence pregnancy outcomes—such as diet, physical activity, or disease prevalence. To address these concerns, I exploit high-frequency variation in heatwave occurrence across municipalities and months over time, and estimate fixed effects models of the following form:

$$Y_{impt} = \sum_{j=1}^3 \beta_j H_{impt}^{(j)} + X'_{impt}\theta + \alpha_p + \gamma_{mt} + \varepsilon_{impt}, \quad (1)$$

where  $Y_{impt}$  denotes a health outcome for newborn  $i$  in municipality  $p$ , born in month  $m$  and year  $t$ ;  $H_{impt}^{(j)}$  measures exposure to heatwaves during trimester  $j$  of pregnancy;  $X_{impt}$  is a vector of individual-level controls;  $\alpha_p$  are municipality fixed effects; and  $\gamma_{mt}$  are month-by-year fixed effects. Standard errors are clustered at the municipality level to allow for spatial correlation in exposure to temperature shocks.

Table 1: Table 1. Summary Statistics for Birth, Maternal, and Heat Exposure Variables, 2012–2021

	Mean	SD	Min	Max	Obs.
Birth weight (grams)	3140.48	631.42	42.00	6500.00	461251
Gestational age (weeks)	38.48	2.64	17.00	46.00	472613
Not Cesarean delivery (share)	0.72	0.45	0.00	1.00	472613
<b>Panel B: Maternal characteristics</b>					
	Mean	SD	Min	Max	Obs.
Mother's age (years)	31.98	5.79	12.00	60.00	472613
Number of children in household	1.76	0.91	1.00	14.00	472613
Foreign-born mother (share)	0.30	0.46	0.00	1.00	472613
Married (share)	0.53	0.50	0.00	1.00	472613
Multiple birth (share)	0.03	0.18	0.00	1.00	472613
Male newborn (share)	0.51	0.49	0.00	1.00	245146
<b>Panel C: Heat exposure</b>					
	Mean	SD	Min	Max	Obs.
Any heatwave during pregnancy (p95, $\geq 3$ days)	0.78	0.42	0.00	1.00	472613
Heatwave in 1st trimester (share)	0.51	0.50	0.00	1.00	472613
Heatwave in 2nd trimester (share)	0.52	0.50	0.00	1.00	472613
Heatwave in 3rd trimester (share)	0.49	0.50	0.00	1.00	472613
Heatwave days during pregnancy (mean)	43.12	124.83	0.00	9240.00	472613
Mean Tmax during pregnancy ( $^{\circ}\text{C}$ )	21.39	3.00	8.40	36.05	429636

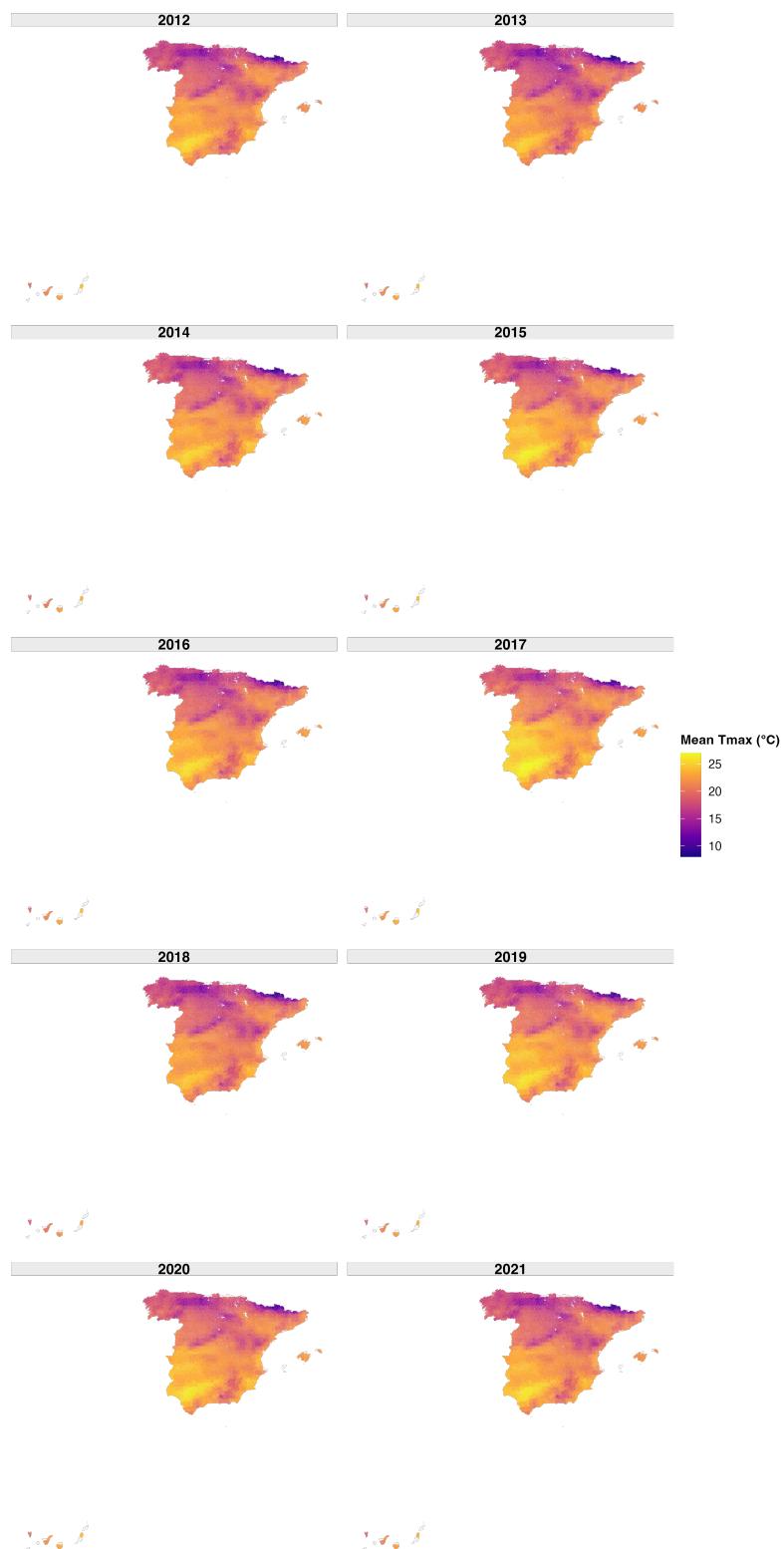


Figure 2: Map of Distribution of Maximum Temperatures in Spain 2012-2021

The model is estimated separately for three outcomes: (i) birth weight (grams), (ii) gestational age (weeks), and (iii) cesarean delivery (binary). For the continuous outcomes I use OLS, and for the binary outcome I estimate a linear probability model. The identifying variation comes from short-term deviations in heatwave incidence within municipalities across months and years, after controlling for time-invariant local characteristics (e.g., housing quality, long-run climate) and for nationwide seasonality and time trends through month-by-year fixed effects. As a result, the coefficients  $\beta_j$  capture the average within-municipality effect of additional heatwave exposure during each trimester of gestation.

The main explanatory variable,  $H_{impt}^{(j)}$ , is defined according to the Spanish Meteorological Agency's concept of a heatwave: a period of at least three consecutive days with daily maximum temperature above the municipality-specific 95th percentile of the historical temperature distribution. I also test alternative definitions based on thresholds at the 90th and 99th percentiles, and on absolute cutoffs (e.g., three or more consecutive days above 35°C). In baseline specifications,  $H_{impt}^{(j)}$  is a dummy equal to one if a heatwave occurred during trimester  $j$ ; I later replace it with the total number of heatwave days to capture dose-response effects. This flexible approach ensures that results are not driven by any particular operational definition of extreme heat.

The vector of controls,  $X_{impt}$ , includes maternal age (and age squared), education, parity, marital status, foreign-born status, multiple birth, and the sex of the newborn. These variables absorb demographic and socioeconomic heterogeneity that could correlate with both fertility and health outcomes. Including the newborn's sex also accounts for biological differences in fetal responses to environmental stressors.

Potential threats to identification include unobserved factors correlated with both heat and pregnancy outcomes. For example, regional differences in housing insulation or access to air conditioning could mitigate heat exposure effects, and behavioral responses—such as reduced mobility or increased rest during heatwaves—might alter the relationship between temperature and fetal growth. While such mechanisms may affect the magnitude of the estimated coefficients, the inclusion of municipality and month-by-year fixed effects removes bias from time-invariant housing conditions and from any national seasonal pattern in maternal behavior. Moreover, the short gestational exposure window limits the scope for reverse causality or endogenous timing of conception in response to anticipated temperature shocks.

Following recent work exploiting quasi-random weather fluctuations to estimate causal effects of temperature on human behavior and welfare outcomes (e.g., Zivin and Neidell, 2014; Schaller et al., 2023; Cohen and Gonzalez, 2024; Santonja et al., 2025), this empirical strategy uses a high-dimensional fixed effects framework to isolate exogenous short-term variation in local temperatures. Conditional on fixed effects and observable controls,

daily and monthly deviations in temperature within municipalities are as-good-as-random with respect to unobserved determinants of birth outcomes. This design therefore purges confounding from both spatial heterogeneity (e.g., persistent climatic, infrastructural, or socioeconomic factors) and common temporal shocks (e.g., nationwide seasonal or policy changes), providing a credible basis for causal interpretation of the estimated coefficients.

To further assess identification, I conduct several specification diagnostics and robustness exercises. First, the assumption that local weather fluctuations are quasi-random conditional on fixed effects and controls is well supported in the meteorological literature. Daily temperature shocks are largely driven by atmospheric variability and are orthogonal to individual-level fertility decisions or local socioeconomic conditions within such short time horizons.

Standard errors are clustered at the municipality level to account for spatial and serial correlation in exposure to temperature shocks, following common practice in weather–health research. As a robustness check.

## 5 Results

### 5.1 Main Results

Table 2 presents the main estimates of the effect of heatwave exposure during pregnancy on birth outcomes. Panel A shows that experiencing at least one heatwave—defined as three or more consecutive days above the local 95th percentile of maximum temperature—significantly increases all three outcomes. Birth weight rises by roughly 174 grams, gestational length by about one week, and the probability of cesarean delivery by 3.5 percentage points. These coefficients are statistically significant at the one-percent level and remain stable across specifications, suggesting that prenatal exposure to heat is positively associated with both fetal growth and the likelihood of surgical delivery.

Panel B disaggregates exposure by trimester. The estimates indicate that the effects are concentrated late in pregnancy: a third-trimester heatwave increases birth weight by nearly 199 grams and gestational age by 1.2 weeks, compared with smaller effects of roughly 45 grams and 0.24 weeks for exposure earlier in gestation. The impact on cesarean delivery follows a similar pattern, rising by 3.3 percentage points for late-gestation exposure. This trimester gradient suggests that heat acts primarily through mechanisms operating near the end of pregnancy—such as changes in maternal rest, hydration, or clinical management of delivery—rather than through early-gestation biological impairment.

The magnitude of these estimates is economically and clinically meaningful. A 200-gram increase in birth weight corresponds to roughly one-third of a standard deviation, comparable to the effects of major policy interventions on prenatal health. A one-week increase in gestational length represents about 0.55 of a standard deviation, a large and clinically relevant improvement. Finally, the 3.5–3.8 percentage point rise in cesarean delivery reflects roughly 0.25 of a standard deviation in the cesarean rate. The results are therefore not only statistically robust but also substantial in magnitude, pointing to meaningful changes in maternal or clinical conditions during heat exposure.

Figure 3 visualizes these trimester-specific estimates. The pattern is clear: exposure to heatwaves during the first or second trimester has modest effects, whereas third-trimester exposure leads to a substantial and precisely estimated increase in birth weight. The sharp rise in the third trimester underscores that the timing of exposure is crucial and supports mechanisms operating late in pregnancy, such as increased rest, hydration, or medical supervision.

In contrast to the international evidence, which typically documents adverse effects of high temperatures on fetal development, these findings reveal a positive relationship in the Spanish context. The stability of the estimates across specifications supports the interpretation that moderate heat exposure may improve intrauterine conditions through adaptive behavioral or institutional responses that offset physiological stress. Subsequent sections test the robustness of these results to alternative heatwave definitions and examine heterogeneity patterns that shed light on potential mechanisms.

## 5.2 Robustness to Alternative Heatwaves Definitions

Tables 3 and 4 test the robustness of the main results to alternative definitions of extreme heat. In Table 3, heatwaves are defined as three or more consecutive days above the 90th percentile of the local temperature distribution, while Table 4 adopts a more restrictive definition based on the 99th percentile. Across both specifications, the estimated effects remain positive, statistically significant, and of comparable magnitude to the baseline results in Table 2, confirming that the findings are not sensitive to the precise operationalization of heat exposure.

Panel A of Table 3 shows that exposure to a p90 heatwave during pregnancy increases average birth weight by 213 grams, gestational age by 1.25 weeks, and the probability of cesarean delivery by 5.2 percentage points. Panel B again indicates that effects are concentrated in late gestation: third-trimester exposure raises birth weight by 284 grams and gestational length by 1.7 weeks. These coefficients are slightly larger than those obtained under the p95 definition, consistent with the broader and more frequent nature

Table 2: Table 2. Effect of Heatwave Exposure During Pregnancy on Birth Outcomes

	(1) Birth weight	(2) Gestational age	(3) C-section
<b>Panel A: Any heatwave during pregnancy (p95, <math>\geq 3</math> days)</b>			
Any heatwave during pregnancy (p95, $\geq 3$ days)	174.093*** (15.693)	1.011*** (0.095)	0.035*** (0.004)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.136	0.134	0.072
<b>Panel B: Trimester-specific heatwave exposure (p95, <math>\geq 3</math> days)</b>			
Heatwave in 1st trimester	44.703*** (5.688)	0.247*** (0.031)	0.016*** (0.002)
Heatwave in 2nd trimester	46.006*** (4.504)	0.239*** (0.025)	0.015*** (0.002)
Heatwave in 3rd trimester	198.555*** (15.667)	1.187*** (0.094)	0.033*** (0.003)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.154	0.169	0.073

Notes: All regressions include municipality and month×year fixed effects. Controls: maternal age (and squared), parity proxy, education (ESTUDIOM), marital status, foreign-born, multiple birth, and sex of newborn. Standard errors clustered at the municipality level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

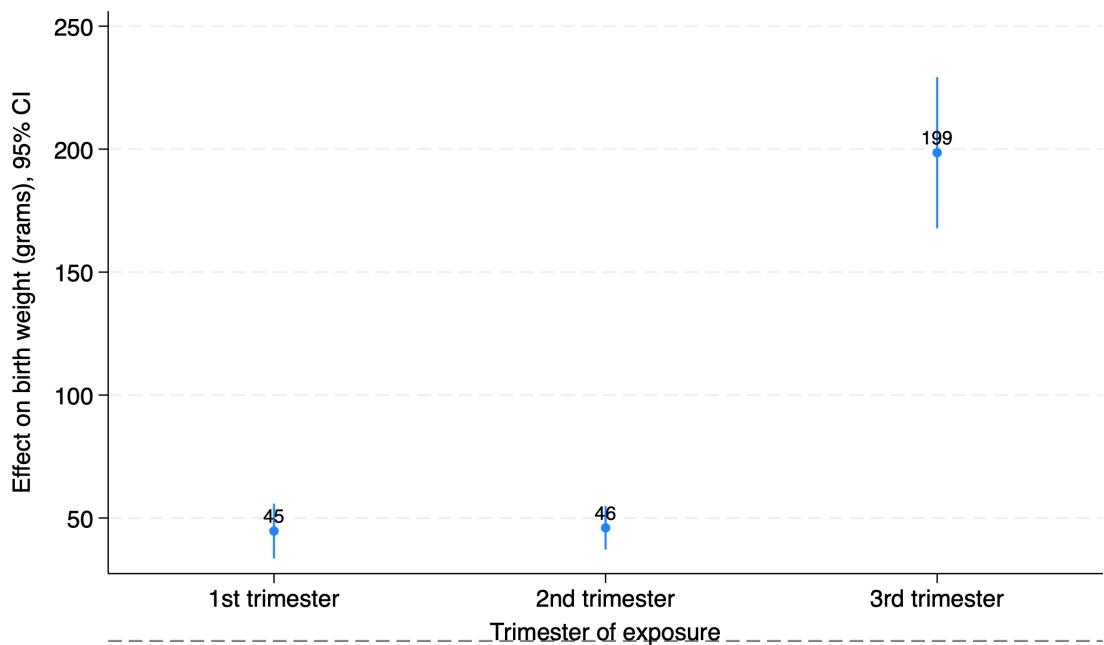


Figure 3: Effect of Trimester-Specific Heatwave Exposure on Birth Weight

Notes: The figure plots point estimates and 95% confidence intervals from the specification in Table 2, Panel B. Each coefficient represents the effect of experiencing at least one heatwave ( $p95, \geq 3$  days) during the specified trimester of gestation. Vertical bars denote 95% confidence intervals based on standard errors clustered at the municipality level.

of p90 heatwaves, which capture moderate but more sustained exposure.

Results under the p99 definition, reported in Table 4, are remarkably similar. Even when focusing exclusively on the most extreme temperature events, exposure to heatwaves continues to increase both fetal growth and gestational duration. Third-trimester exposure to a p99 heatwave increases birth weight by roughly 136 grams and gestational length by 0.8 weeks, while cesarean deliveries rise by about 2.6 percentage points. The persistence of these effects under increasingly stringent thresholds demonstrates that the positive relationship between heat exposure and neonatal outcomes is not an artifact of a particular cutoff or sample composition, but a robust empirical pattern.

Taken together, these robustness exercises reinforce the credibility of the main findings: independent of how heatwaves are defined, exposure to unusually high temperatures during pregnancy—especially in the final trimester—is consistently associated with heavier and longer-lasting pregnancies. The stability of the estimates across thresholds also mitigates concerns that the results are driven by measurement error or arbitrary classification of extreme heat.

Consistent with a dose–response pattern, Appendix Figure A1 shows that pregnancies exposed to a greater number of heatwave days experience progressively higher birth weights.

### 5.3 Heterogeneity

Table 5 explores whether the positive effects of prenatal heat exposure on birth weight vary across socioeconomic groups, locations, and by the sex of the newborn. The goal is to assess both heterogeneity in treatment effects and to gain insights into potential mechanisms underlying the main results.

Panel A compares mothers with low versus high education levels. The coefficients are remarkably similar—165 grams and 180 grams, respectively—indicating that the increase in birth weight following heatwave exposure is not driven by differences in maternal education or socioeconomic status. This pattern suggests that the observed effects are unlikely to reflect compositional or behavioral differences linked to income or knowledge and are instead consistent with physiological or contextual adaptations common across groups.

Panel B splits the sample by settlement size. The estimates show that the effect is considerably stronger in large urban areas (+243 g) than in small towns or villages (+137 g). This difference points to environmental and behavioral channels related to heat exposure and mitigation. Urban areas experience more intense and sustained heat due to the urban heat island effect, but also greater access to cooling, medical services, and prenatal mon-

Table 3: Table 3. Effect of Heatwave (p90) Exposure During Pregnancy on Birth Outcomes

	(1) Birth weight	(2) Gestational age	(3) C-section
<b>Panel A: Any heatwave during pregnancy (p90, <math>\geq 3</math> days)</b>			
Any heatwave during pregnancy (p90, $\geq 3$ days)	213.364*** (50.783)	1.250*** (0.319)	0.052*** (0.007)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.131	0.124	0.072
<b>Panel B: Trimester-specific heatwave exposure (p90, <math>\geq 3</math> days)</b>			
Heatwave in 1st trimester	36.227*** (10.011)	0.183*** (0.060)	0.014*** (0.002)
Heatwave in 2nd trimester	38.993*** (9.501)	0.196*** (0.056)	0.015*** (0.002)
Heatwave in 3rd trimester	283.906*** (22.963)	1.729*** (0.141)	0.044*** (0.003)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.162	0.189	0.073

Notes: All regressions include municipality and month×year fixed effects. Controls: maternal age (and squared), parity proxy, education (ESTUDIOM), marital status, foreign-born, multiple birth, and sex of newborn. Standard errors clustered at the municipality level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

Table 4: Table 4. Effect of Heatwave (p99) Exposure During Pregnancy on Birth Outcomes

	(1) Birth weight	(2) Gestational age	(3) C-section
<b>Panel A: Any heatwave during pregnancy (p99, <math>\geq 3</math> days)</b>			
Any heatwave during pregnancy (p99, $\geq 3$ days)	158.079*** (12.343)	0.910*** (0.073)	0.036*** (0.003)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.140	0.141	0.072
<b>Panel B: Trimester-specific heatwave exposure (p99, <math>\geq 3</math> days)</b>			
Heatwave in 1st trimester	68.491*** (5.451)	0.419*** (0.031)	0.022*** (0.002)
Heatwave in 2nd trimester	84.430*** (6.488)	0.459*** (0.037)	0.021*** (0.002)
Heatwave in 3rd trimester	135.918*** (10.945)	0.788*** (0.063)	0.026*** (0.002)
Observations	460,328	471,587	471,587
Adj. R <sup>2</sup>	0.141	0.142	0.073

Notes: All regressions include municipality and month×year fixed effects. Controls: maternal age (and squared), parity proxy, education (ESTUDIOM), marital status, foreign-born, multiple birth, and sex of newborn. Standard errors clustered at the municipality level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

itoring. The stronger effects in cities therefore suggest that adaptive responses—such as increased rest, air conditioning use, or proactive medical supervision—may amplify the positive association between heat and fetal growth.

Panel C examines heterogeneity by the sex of the newborn. Male and female infants exhibit comparable responses to heatwave exposure, with slightly larger estimates for males (+182 g versus +165 g). This pattern aligns with medical evidence that male fetuses are more sensitive to environmental conditions, potentially displaying stronger growth responses when the intrauterine environment improves or stressors are mitigated. The similarity across sexes nonetheless indicates that the overall mechanism operates broadly rather than being sex-specific.

Overall, these findings reveal limited socioeconomic heterogeneity but some variation across environments, consistent with adaptive behavioral or institutional mechanisms rather than purely biological ones. The larger effects in urban settings in particular suggest that factors such as access to cooling technologies, behavioral adaptation, and clinical management during hot periods may play a key role in shaping how heat exposure affects fetal growth in Spain. At the same time, these heterogeneity patterns should be interpreted as suggestive rather than definitive evidence of mechanisms, as the data do not directly capture behavioral or medical responses during pregnancy.

## 6 Policy Implications and External Validity

The Spanish context—universal prenatal care, high urbanization, and widespread access to cooling—likely mediates the relationship between heat and fetal development. The positive effects on birth weight and gestational length suggest that behavioral and clinical adaptations (rest, hydration, AC use, intensified monitoring) may offset physiological stress for most pregnancies. This has three implications. (i) Prenatal guidance during heat: simple, low-cost advice (hydration, reduced exertion, scheduling ANC visits during heat alerts) may be effective. (ii) Targeting: heterogeneity points to stronger effects in large cities; local heat-health plans could explicitly include pregnant women (access to cooled spaces, targeted messaging). (iii) Read-across to other settings: where cooling or prenatal access is limited, effects could revert toward the adverse patterns documented elsewhere. Future work should quantify how adaptation inputs (AC penetration, housing quality, leave policies) mediate temperature–health gradients to inform scalable interventions.

Table 5: Heterogeneity and Mechanisms

	(1)	(2)
<b>Panel A: By maternal education (Birth weight)</b>		
<i>Columns: Low vs High education</i>		
Any heatwave during pregnancy (p95, $\geq 3$ days)	165.012*** (15.195)	179.971*** (18.992)
Observations	142,070	111,130
Adj. R <sup>2</sup>	0.125	0.156
<b>Panel B: Large of Cities (Birth weight)</b>		
<i>Columns: Village/Town (<math>\leq 20k</math>) vs Big City (<math>&gt; 100k/capital</math>)</i>		
Any heatwave during pregnancy (p95, $\geq 3$ days)	136.596*** (17.264)	243.124*** (20.989)
Observations	171,860	136,695
Adj. R <sup>2</sup>	0.128	0.148
<b>Panel C: By sex of newborn (Birth weight)</b>		
<i>Columns: Female vs Male</i>		
Any heatwave during pregnancy (p95, $\geq 3$ days)	165.724*** (14.861)	182.046*** (17.051)
Observations	221,500	238,741
Adj. R <sup>2</sup>	0.133	0.129

Notes: Each column reports the coefficient on *Any heatwave during pregnancy (p95,  $\geq 3$  days)*. All specifications include municipality and month×year fixed effects. Controls (when available): maternal age (and squared), parity proxy, marital status, foreign-born, multiple birth, sex of newborn, and education dummies. Standard errors clustered at the municipality level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

## 7 Conclusion

This paper provides new evidence on the relationship between gestational heat exposure and health at birth, using administrative microdata from Spain linked to high-resolution meteorological records. In contrast to much of the existing literature, which finds that extreme heat impairs fetal development, I show that exposure to heatwaves during pregnancy—particularly in the third trimester—increases both birth weight and gestational length, with modest increases in the probability of cesarean delivery. These results are robust to a wide range of specifications and alternative definitions of extreme heat, and their magnitude is economically and clinically meaningful. The findings highlight that the effects of temperature on fetal development are context-dependent and shaped by adaptation, behavior, and institutions.

The paper makes three main contributions. First, it adds large-scale, high-frequency evidence from Southern Europe to the climate–health literature, a region where heat exposure is both increasingly frequent and under-studied. Second, it challenges the prevailing view that higher temperatures uniformly harm fetal growth, suggesting instead that moderate exposure in a high-adaptation environment can have neutral or even beneficial effects. Third, it demonstrates the value of combining administrative health data with detailed meteorological information to isolate short-run causal effects of environmental shocks.

At the same time, the study faces limitations that open avenues for future research. The analysis relies on outdoor temperature measures and does not observe indoor exposure, air conditioning availability, or maternal time use, which likely mediate physiological stress and adaptation. Nor can it capture changes in work intensity or medical leave during pregnancy, which may explain part of the observed patterns. Future work using micro-level data on housing conditions, occupational exposure, and maternal behavior could shed light on these mechanisms and on the broader question of how societies adapt to rising temperatures.

As climate change continues to increase the frequency and intensity of heatwaves, understanding how heat exposure interacts with local adaptation and healthcare systems is essential for designing effective public health responses. The evidence from Spain suggests that with adequate behavioral and institutional buffers, the short-term effects of heat on fetal development need not be negative—but sustaining this resilience in a warming world will require continued attention from both researchers and policymakers.

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# Appendix

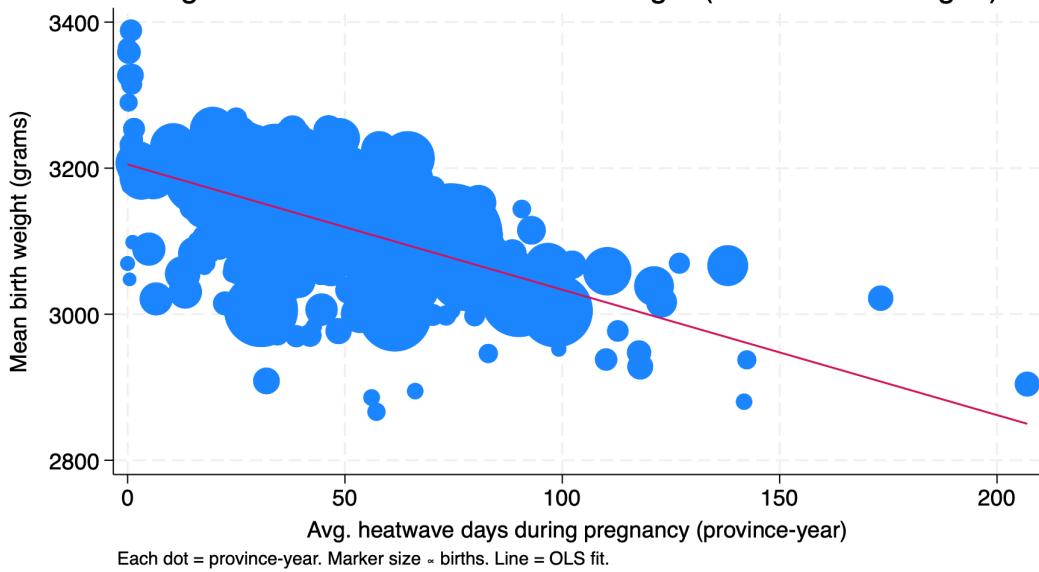
Table A1: Covariate Balance: Pregnancies With vs. Without Heatwave Exposure

	No heatwave	$\geq 1$ heatwave	Diff.	p-value
<b>Panel A: Maternal characteristics</b>				
Maternal age (years)	31.73	32.05	0.32	0.000
Education: High (share)	0.21	0.25	0.04	0.000
Foreign-born (share)	0.32	0.30	-0.02	0.000
<b>Panel B: Birth outcomes</b>				
Birth weight (grams)	3107.49	3149.88	42.4	0.000
Gestational age (weeks)	38.20	38.55	0.35	0.000

*Notes:* Means by exposure group. p-values from two-sided t-tests of equal means.

Exposure indicator: any heatwave during pregnancy (p95,  $\geq 3$  days).

**Figure A5. Heatwaves vs. Birth Weight (Provincial averages)**



**Figure A1: Heatwave and Weight Relation at Province Level**

**Table A2: Table 6. Mechanisms: Stillbirth and Perinatal Mortality**

	(1)	(2)
<b>Panel A: Regression results</b>		
<i>Columns: Stillbirth vs Perinatal death</i>		
Any heatwave during pregnancy (p95, $\geq 3$ days)	0.000 (.)	0.000 (0.000)
Observations	472,572	472,572
Adj. R <sup>2</sup>	.	-0.001

Notes: Each column reports the coefficient on *Any heatwave during pregnancy (p95,  $\geq 3$  days)*. The dependent variable is an indicator for stillbirth (col 1) or perinatal death (col 2). All specifications include municipality and month $\times$ year fixed effects. Controls: maternal age (and squared), parity proxy, marital status, education, foreign-born, multiple birth, and sex of newborn. Standard errors clustered at the municipality level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

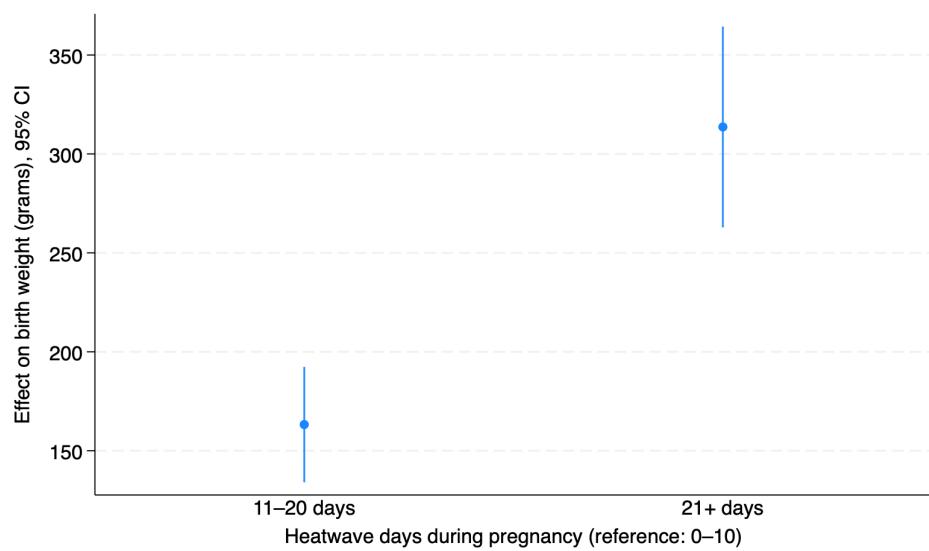


Figure A2: Dose Effect of HEatwaves on Birth Weight