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# Temperature and Fertility: Evidence from Spanish Register Data

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# Temperature and Fertility: Evidence from Spanish Register Data

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**Abstract**

In this paper, we combine administrative data for continental Spain from 2010 to 2018 with meteorological data to identify the effect of temperature on fertility. We demonstrate that warm (25-30°C) and hot days (>30°C) decrease total fertility rate (TFR) in Spain, and that the estimated decrease is higher than the effects estimated in previous literature for other countries. Moreover, we show that locations with a colder climate are more vulnerable to the impact of heat. Our results suggest that the global impact of climate change on population dynamics may be understated, especially without adaptation and mitigation measures, and that temperature increases may exacerbate the socio-economic consequences of low fertility such as population ageing.

Keywords: Fertility, TFR, temperature, heat, Spain.

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## Introduction

Climate change and its associated extreme meteorological events have become pivotal challenges for human populations in the twenty-first century. The year 2022, for example, has been the hottest ever recorded across many European countries, coming after a series of already extremely hot years over the last two decades. The increasing – and likely unceasing -- escalation of extreme climatic events has led to calls for urgent action to mitigate their effects, as well as for a better understanding of the possible population impacts in the decades ahead.

A vast body of literature has investigated the impact of climate change and extreme temperatures on various population outcomes, including mortality (Carleton et al., 2020; Conte Keivabu, 2022; Stafoggia et al., 2006; Masiero et al., 2022), infant health (Chen et al., 2020; Conte Keivabu & Cozzani, 2022; Le & Nguyen, 2021), adult health (Bai et al., 2014; Barreca & Shimshack, 2012), income (Isen et al., 2017), educational attainment (Randell & Gray, 2019; Wilde et al., 2017), and migration (Hoffmann et al., 2021). Surprisingly, there has been far less attention given to the impact of climate change on fertility, with only a handful of studies conducted so far (Hajdu & Hajdu, 2020; Grace, 2017). Specifically, two studies were conducted in the US (Barreca et al., 2018; Lam & Miron, 1996), one in South Korea (Cho, 2020), one in Hungary (Hajdu & Hajdu, 2022), and one that pooled together data from sub-Saharan Africa (Thiede et al., 2022). Overall, these studies find a reduction in fertility eight-to-ten months after abnormally hot days.

However, this literature contains significant gaps. First, much of this literature analyzes aggregate birthrates at the sub-national level without exploring heterogeneous patterns within these populations, often due to lack of relevant data. While useful in determining the population-level effects of temperature variation, it is important to elucidate possible heterogeneous effects by age, parity, and socioeconomic status to understand the stratified effects of climate change on individuals. This is particularly important since there are cogent theoretical arguments that certain populations are better able to mitigate temperature shocks. Individuals with low economic resources or with lower socioeconomic status may lack access to mitigation technologies such as fans and air conditioning, live in housing units which are poorly insulated from temperature variations, or work in professions which are more likely to be outdoors, such as construction or agriculture. Thiede et al., (2022) use microdata to explore these heterogeneities, but their analysis only uses annual variation in temperatures rather than the high-frequency daily shocks aggregated to the monthly level preferred in this literature (see Dell et al 2014) to understand trimester- or month-specific temperature effects. Conversely, Cho (2020) uses aggregated, sub-national data on maternal characteristics to explore whether the fraction of mothers of certain groups changed with temperature, but does not find any significant heterogeneities by mother's age or socioeconomic status.

Second, this literature lacks attention to heterogeneous effects across contexts. Most of the studies either focus on locations which are 1) high income and with high AC penetration (US and South Korea), or 2) small areas with heterogeneous climatic zones (South Korea and Hungary). Only Thiede et al (2022) looks broadly at a low-AC penetration context with broad differences in climate in its pan-African analysis, but such heterogeneities are not explored within their study. For example, many of these studies posit parental reproductive health as a major possible mechanism driving the fertility effects, yet lack any direct evidence on the role of parental SES in the temperature-fertility relationship.

In this article, we provide new evidence on the link between temperature and fertility. Using data from Spanish registers between 2010 and 2018, we study this relationship across climatic zones, maternal age groups, and educational levels. We also analyze heterogeneity by parental characteristics. To this aim, we draw birth counts and total fertility rate (TFR) from Spanish population-wide birth registers and statistics on resident population, and we create a province-by-month dataset, which we combine with fine-grained meteorological data provided by the Copernicus Data Store.

While previous research made important contributions on specific margins, we combine many of the strengths from previous research into a single study, allowing us to advance and complement the understanding of the relationship between extreme temperatures and fertility. First, whereas studies from the United States were typically done at the state level, we study the relationship between temperatures and fertility at a finer spatial resolution of analysis (provincial level or NUTS-3), similarly to Hajdu & Hajdu (2022). Second, since we draw on population registers which provide detailed information on the socio-demographic characteristics of mothers and fathers, we are able to study the effect of temperatures across different population groups, similarly to Cho (2020). Studying the heterogeneous consequences of extreme temperatures on fertility across different groups is particularly important to understand how climate change many exacerbate pre-existing socioeconomic inequalities, and identify vulnerable groups which may experience the harsher consequences of climate on their fertility outcomes and reproductive goals. Fourth, we study whether the effect of temperatures on fertility is recuperated ten-to-fifteen months after the exposure to exceptionally hot days. Finally, the Spanish context itself is an interesting case study. It has one of the lowest fertility levels in Europe (Reher, 2021), where climate change is accelerating at one of the fastest rates in the Mediterranean area (Cramer et al., 2018; Perkins-Kirkpatrick & Lewis, 2020), as well as being an area with very low air conditioning penetration and therefore particularly vulnerable to the consequences of extreme temperatures.

## Conceptual framework

### *Temperature, fertility, and their variation by population groups*

There are at least three possible links between ambient temperature and fertility: health and reproductive health, behaviors, and individual preferences. Temperatures have been proved to affect health and reproductive health, impacting the chances of conceiving and successfully carrying a child to term. Research has shown that spermatogenesis, menstrual cycles, and oocyte development have seasonal patterns, while the negative consequences of heat on reproductive health has been hypothesized to be more detrimental for males (Barreca et al., 2018; Rojansky et al., 1992; Hansen, 2009). Extreme temperatures are also related to health in general. Heatwaves and humidity levels have been linked to an increased probability of becoming ill (i.e. influenza, dizziness, headaches, heat strokes and exhaustion), with these risks being higher for males than females, and for individuals already having pre-existing health conditions (Bai et al., 2014; Barreca & Shimshack, 2012). These temperature-related health hazards may consequently impact fecundity and sexual intercourse, possibly impacting overall fertility. Moreover, since individuals from low socio-economic backgrounds are more likely to be in a poorer health (Mackenbach et al., 2008), the health-related consequences of heat may be more severe for this group. Finally, contraceptive efficacy may decrease with high temperatures and in relation to prior health (see Barreca et al., 2018 for a discussion). Therefore, low SES individuals are possibly more likely to face the temperature-related risk of contraceptive failure and the subsequent risk of unwanted conceptions (Burkman et al., 2009; Ranjit et al., 2001).

High temperatures may also influence behaviours such as the frequency of sexual intercourse within couples. In the United States, Google searches related to mate-seeking behaviours exhibit a seasonal pattern, which some hypothesize are driven by temperature's effect on sexual desire (Markey & Markey, 2013). Yet, empirical evidence from studies directly investigating the relationship between temperatures and intercourse is more mixed. On one hand, Wilde et al. (2017) found the number of women reporting to be sexually active decreased with temperature in sub-Saharan Africa. On the other hand, Hajdu & Hajdu (2019) found no such association in Hungary.

There is also evidence that certain groups have systematic differences in birth timing. For example, planned pregnancies are more likely to result in a spring birth, which births are also associated with higher maternal socio-economic status, older maternal age, being in union, and better maternal health. This is not the case among unwanted pregnancies and lone mothers (Clarke et al., 2019; Buckles & Hungerman, 2013). Some of the first theoretical explanations of birth seasonality focused on preferences for births during specific seasons. For example, some have hypothesized that an excess of spring births in the past were driven by farmers timing marriages or conceptions to immediately follow the harvest, when food was plentiful and agricultural labor was less needed, resulting in spring and early summer births. See Ellision et al. (2005) for an extensive review. If individuals prefer a particular season of birth, we may expect to see this at the population level. Moreover, since most explanations for seasonality of birth preferences would only hold for certain population subgroups, we may expect to see heterogeneous births by socioeconomic status. However, these preferences could be due to several factors, only one of which could be temperature. We are not aware of any study that directly tests whether individual preferences for a specific season of conception are due to temperature-related preferences, such as trying to avoid pregnancies during higher temperature months. However, evidence from the geography of birth seasonality in Australia points to climatic patterns as a possible explanation (Wilson et al., 2020). On the other hand, a study focused on Sweden found a decrease in seasonality over time suggesting social factors rather than environmental to drive preferences in the timing of births (Dahlberg & Andersson, 2018).

*Spanish climate*

In this study, we focus on 48 provinces on continental Spain. The total number of Spanish provinces is 52 but we exclude the provinces of Ceuta, Melilla, Santa Cruz De Tenerife and Las Palmas for which we lack information on air pollution. These provinces a host varying climatic conditions, and are expected to be detrimentally affected by climate change. Spain is comprised of a diverse selection of climatic areas. For example, the northwestern part is exposed to the Atlantic Ocean and hosts an oceanic climate, the southeastern part is described as having an arid climate, the eastern coast has a Mediterranean climate, and the central regions have a continental climate. However, the Spanish climate is rapidly changing, and increasingly experiences exceptionally hot summers. For example, the summers of 2003 and 2015 have been particularly hot (Russo et al., 2015). Moreover, Spain is expected to experience the highest increase in temperatures in Europe (Cramer et al., 2018), as well as the European country which will experience the highest increase in heat-related deaths (Forzieri et al., 2017) and the largest decrease in life expectancy due to climate change (Hauer & Santos-Lozada, 2021). Consequently, Spain is a particularly interesting case to estimate the effects of climate change on fertility.

## Methods

### *Birth Data*

We construct province-by-month total fertility rates (TFR) (2010-2018) combining two data sources: population-level birth registers and population figures, which are both provided by the Spanish Statistical Institute (Instituto Nacional de Estadistica - INE). Birth registers collect high quality information on births in Spain, including socio-demographic characteristic of the parents and delivery information. Population figures are reported by sex, age and province of residence every semester, and are generated by INE from vital, migration, and citizenship acquisition statistics. From these data, we construct our main outcome variable. We use birth counts and population by age (15-49) to create province-by-month TFRs between January 2010 and December 2018. TFR is obtained by the sum of each age-specific fertility rate (ASFR) for each age group between 15 and 49.

### *Meteorological data and control variables*

We use gridded meteorological data provided by the E-OBS and freely available in the Copernicus Data Store (CDS). The E-OBS meteorological data is gathered by a network of weather stations present in Europe, and the daily values are interpolated reaching a resolution of 0.1 degree grid cells (Cornes et al., 2018). The meteorological information is available from 1950 to 2021 and on variables such as mean temperature, relative humidity, wind speed, precipitation, and surface shortwave down welling radiation. In our analysis, we include all such information and construct the province-by-day meteorological measures calculating the average values of the daily grid values falling within the administrative boundaries of each province. Moreover, for the temperature data, we constructed eight temperature bins for each month. Specifically, <0°C; 0 to 5°C; 5 to 10°C; 10 to 15°C; 15 to 20°C; 20 to 25°C; 25 to 30°C; and > 30°C and count the number of days per month in which the daily mean temperature falls within these ranges. For the other meteorological data (i.e. humidity, wind speed, precipitation, and surface shortwave down welling radiation) we average the daily values to create monthly means.

We also gather monthly information on vegetation provided by the CDS and air pollution estimates distributed by the Atmospheric Compositional Analysis Group (ACAG). The vegetation measure we use is the Leaf Area Index (LAI), a common measure of plant canopy present in a specific area extracted using satellite observations. For air pollution we use Particulate Matter 2.5μg/m³ (PM2.5) that is widely used in studies focusing on the negative impact of air quality on health (Colmer et al., 2020). Chemical transport modelling is used to combine measurements from local stations and satellite observations, providing estimates that encompass the entire province (Hammer et al., 2020). Both the LAI and PM2.5 measurements are at a 1km grid resolution, and we average the values falling within each province to compute the province-monthly estimates.

The impact of temperature on fertility could be captured differently. For example, some studies have adopted relative measures of temperature exposure such as deviations from the local mean temperature of a location or using temperature bins based on the percentile distribution in the local temperature (Masiero et al., 2022; Conte Keivabu , 2022; Vicedo-Cabrera et al., 2021). In the robustness checks, we present results replicating the main analysis using temperature percentiles.

As additional control variables, we include population density and GDP per capita at the provincial level provided by INE, and interpolate average yearly values between months.

*Empirical Strategy*

We use an OLS fixed effects models specified as:

$$\mathrm{Ln}[Ypt] = \sum_{\mathrm{j}}^{\mathrm{J}} \sum_{k}^{K} \beta_k^j \, TEMP_{p,t-k}^j + \boldsymbol{X}_{p,t-9} + a_{pm} + \gamma_{py} + \delta_{pq} + \varepsilon_{pt}$$

where our outcome of interest is the logarithm of the monthly TFR in each province and year ($Y_{pt}$), and our variables of interest are temperature as captured by our temperature bin variables and measured at the month of birth and in each of the 15 months prior ($TEMP_{p,t-k}^j$). The temperature bin 10-20°C is set at the reference level and is excluded from the model. We include a set of control variables $\boldsymbol{X}_{p,t-9}$ that we discussed in the previous section and that are measured in the provincial unit in the month of conception ($t$-$9$). Moreover, we include province-by-year and province-by-month fixed effects ($\gamma_{py}$ and $\alpha_{pm}$ respectively). $\delta_{pq}$ is a quadratic trend for the province century month of conception. The use of these fixed effects allows us to account for province-specific seasonal trends and allow for a causal interpretation of our estimates. Finally, we use weights for the number of women of reproductive age (15-49) in the year prior to birth in each province, and cluster standard errors within provincial units

## Results

*Descriptive statistics*

In Table 1, we present descriptive statistics for the monthly variables used in our main analysis. The average monthly TFR is 0.10, implying a yearly TFR of 1.2, consistent with low fertility levels in Spain (Reher, 2021). As expected, the majority of days are within the 10°C to 20°C temperature range, and we see the lowest proportion of days with temperatures >30°C.

Table 1: Descriptive Statistics

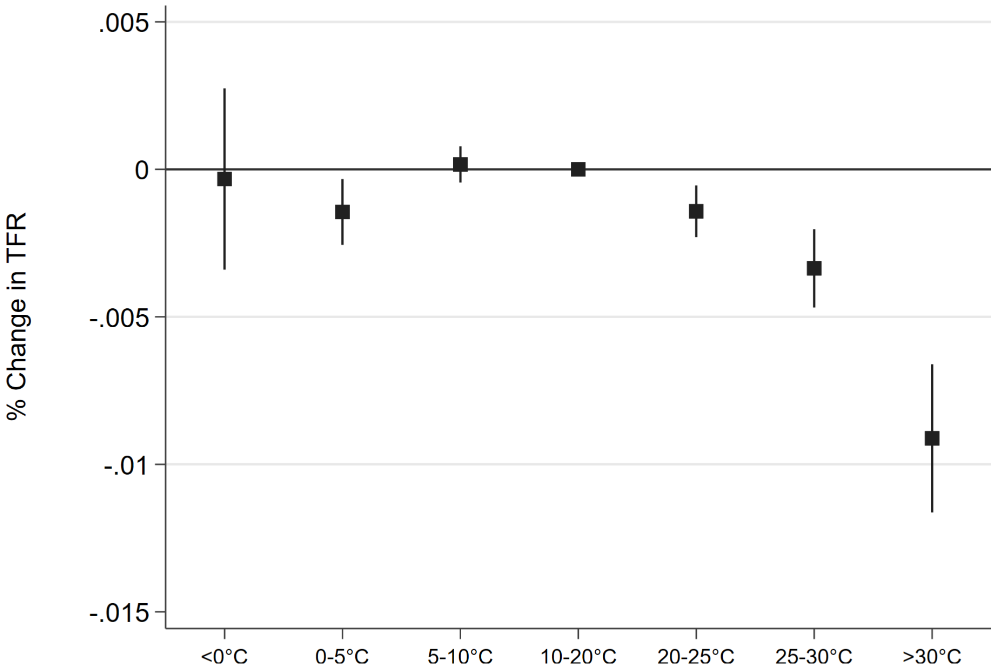
| | Mean | SD | Min | Max |
|---|---|---|---|---|
| Total Fertility Rate | 0.10 | 0.01 | 0.05 | 0.15 |
| Birth counts | 708 | 995 | 34 | 6502 |
| Women in maternal age | 435,288 | 576,302 | 34,351 | 3,370,084 |
| <0°C | 0.24 | 1.12 | 0.00 | 13.00 |
| 0 to 5°C | 2.59 | 5.15 | 0.00 | 30.00 |
| 5 to 10°C | 6.67 | 7.90 | 0.00 | 31.00 |
| 10 to 20°C | 13.44 | 10.36 | 0.00 | 31.00 |
| 20 to 25°C | 5.02 | 7.45 | 0.00 | 31.00 |
| 25 to 30°C | 2.07 | 5.53 | 0.00 | 31.00 |
| > 30°C | 0.11 | 0.80 | 0.00 | 14.00 |
| PM2.5 | 9.64 | 2.31 | 4.29 | 23.06 |
| Relative Humidity | 68.58 | 12.19 | 27.97 | 93.09 |
| Precipitation | 1.59 | 1.53 | 0.00 | 12.31 |
| Solar radiation | 1017.42 | 4.43 | 997.98 | 1032.45 |
| Wind | 0.51 | 0.89 | -2.81 | 4.28 |
| Leaf Area Index | 2.12 | 0.42 | 1.18 | 3.45 |
| Population Density | 122 | 166 | 8 | 816 |
| GDP per capita | 21,894 | 4,686 | 14,568 | 36,436 |

*Note*: We report summary statistics for the monthly values of the variables in our main analysis.

*The effect of temperatures on fertility*

In Figure 1 we show results of our main analysis. We report point estimates and related 95% confidence intervals on the effect of temperature exposure for each temperature bins on the TFR nine months later. We observe a negative effect of hot days on TFR, with the largest negative estimates observed for the temperature bin > 30°C. In line with previous studies, we do not observe cold temperatures to substantially affect fertility (Barreca et al., 2018; Hajdu & Hajdu, 2022): exposure to days with temperatures between 0 and 5°C yields only a small effect. Also, we repeat the analysis using temperature 10 months before, since previous studies have shown effects at this lag as well (Barreca et al., 2018). Similarly, in the supplementary material Figure A2, we show hot days also decrease TFR 10 months after exposure, but with a smaller effect size compared to the nine-month lag in Figure 1.

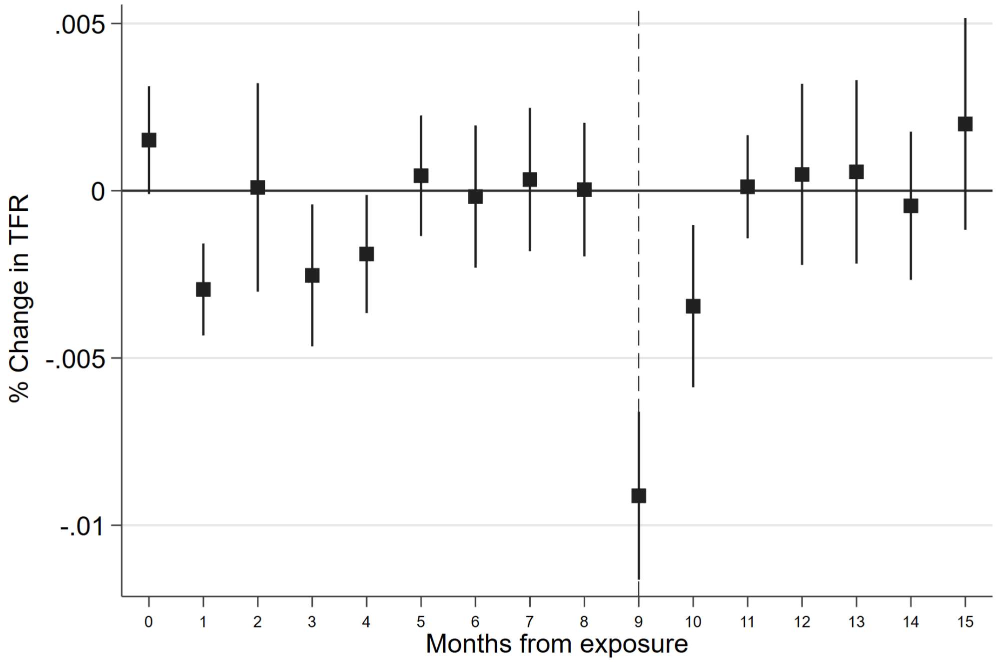
Figure 1: Effect of mean temperature on fertility 9 months after exposure




Note: coefficients are estimate based on equation (1) with 95% confidence intervals. We report only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 & 10-15) are included in the analysis but not reported in figure.

Previous studies have shown birth rebounds in months following the exposure to hot days (Barreca et al., 2018; Hajdu & Hajdu, 2022). We also explore this possibility. and show the results in Figure 2. In this figure, we present the effects of hot days during each month zero to fifteen months prior to birth. If individuals recuperate births averted due to heat, we may expect to observe a positive effect of heat exposure in the months following the negative effect around the nine-month mark. In contrast to previous studies, we do not observe birth recuperation in the months following exposure to an additional day above 30 degrees, and neither for additional 25- and 30-degree days (See Figure A1 in the supplementary material). Therefore, our results suggest an overall net decline in births in our window of analysis. While individuals might recuperate births lost due to high temperatures in the following years and months, no previous research has found significant recuperations at these prolonged time lags.

Figure 2: Effect of a day with temperature >30°C on fertility from 0 to 15 months from exposure.




Note: coefficients are estimated based on equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bin >30°C at different months from exposure. Exposure to the other temperature bins is included in analysis but not reported in the figure.

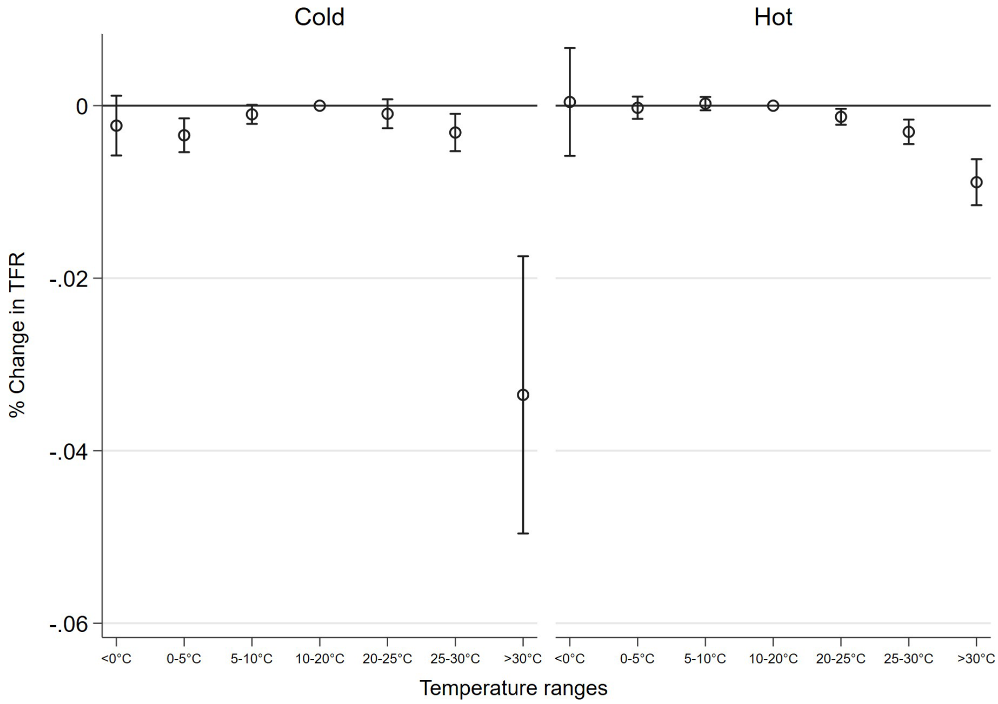
*Heterogeneity: climate, gender, SES and age*

In this section, we explore the heterogeneous effects of temperature by climatic areas, sex of the newborn, maternal educational levels, and maternal age.

Beginning with local climate, there is evidence from the literature that different climatic regions could alter the association between temperature and fertility. For example, (Barreca et al., 2018) found that in colder climatic regions of the US, the impact of hot days on fertility was more substantial than in warmer locations. We perform a similar analysis by classifying Spanish provinces into hot and cold regions, as measure by whether the region is above or below the median temperature region in our sample. In Figure 3, we replicate Figure 1 but add an interaction between the temperature bins and these climate indicators, and plot the coefficients of temperature on TFR 9 months after exposure. Similar to Barreca et al. (2018), we observe a heterogeneous impact of hot days across these zones. For example, the effect of days above

30°C is about three times larger in colder regions compared to hotter ones. Conversely, we do not observe any substantive differences by climatic regions when observing the effect of cold days on fertility.

Figure 3: Temperature effect on fertility by climatic area



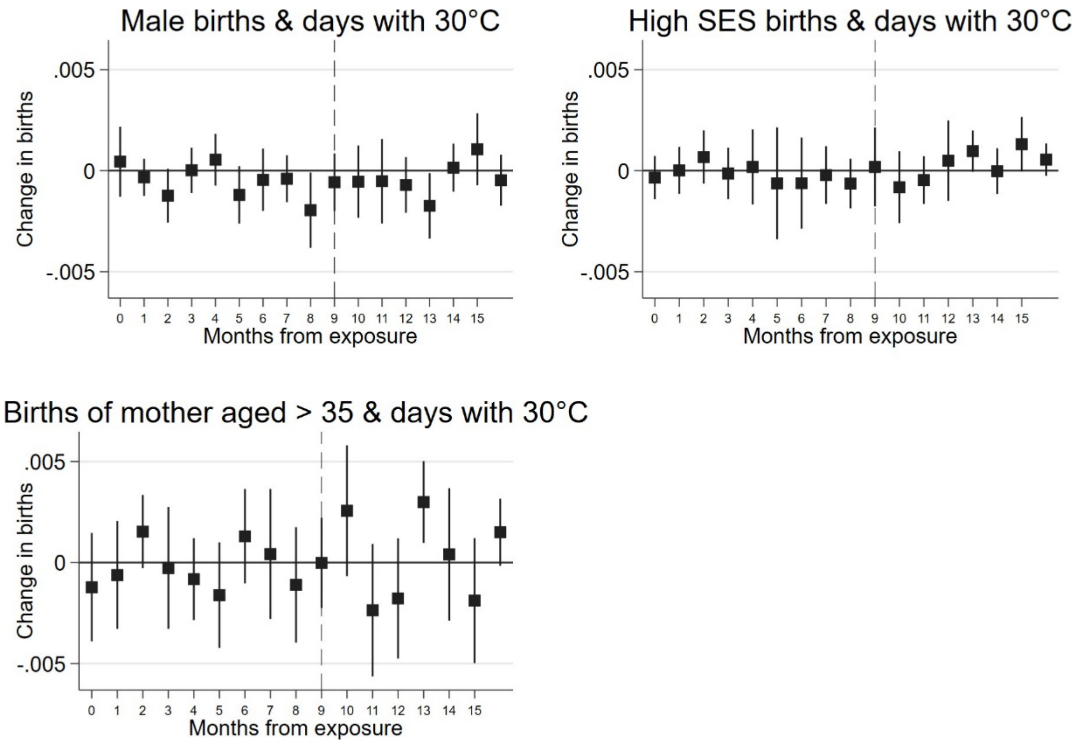

Note: coefficients are estimated based on equation 1 but adding an interaction between temperature bins and climatic regions. We report also 95% confidence intervals. We report only the coefficients for the temperature bin 9 months after exposure. The other temperature bins are present in the analysis but not reported.

To study the heterogeneous effect of temperatures across different population subgroups, we estimate equation (1) using the province-level monthly percentage of male births, the percentage of mothers with university education, and the percentage of births to mothers over age 35 as dependent variables. Results are presented in Figure 4. Beginning with our results for male births, previous research has shown that males are more vulnerable to the exposure to high temperatures in Spain and thus temperatures could potentially lead to disparities in sex ratios (Conte Keivabu & Cozzani, 2022). We observe only a decline in male births eight months after an additional day above 30 degrees, which is consistent with male biological fragility very early in pregnancy.

We do not observe any difference in the impact of days with temperatures above 30°C on the share of births from mothers with a university education nine months later. However, we do observe a positive effect at the 13th and 15th months. This could suggest a faster recuperation in births by high SES mothers compared to other socioeconomic groups. However, since we do not observe completed fertility, recuperation of births for low SES individuals could happen in successive years.

Finally, we explore whether the effect of temperature varies by maternal age, particularly on births from mothers above 35 years of age. The results, shown in the lower-left panel of Figure 4, suggests no age differences in the impact of hot days on fertility after 9 months. However, we observe a larger recuperation of births for mothers aged above 35 at the 13th month.

Figure 4: Effect of days with temperature >30°C on the prevalence of births by socio-demographic groups.




Note: coefficients for the temperature bin >30°C are estimated based on equation 1 but using as an outcome the proportion of male births, high SES births and mothers aged above 35. The other temperature bins are included in the model but not reported in the figure. We report coefficients with 95% confidence intervals.

*Effect Size*

In Table 2 we provide a comparison of the effect size found in figure 1 with those in existing comparable studies. This is not straightforward -- even though most of these studies use temperatures bins to estimate the effect of heat on fertility, there are differences in their estimation strategies which we list here. Studies by Barreca et al. (2018), Hajdu & Hajdu (2022), and Cho (2020) adopt a similar empirical strategy to ours, but differ in the measurement of temperature exposure. For example, Barreca et al. (2018) use 26.6°C as the threshold for the highest temperature and Cho (2020) used maximum temperature instead of mean temperature. In addition, Barreca et al., (2018) and Hajdu & Hajdu (2022) use weekly data on births rather than monthly as in our study and Cho (2020).

Compared to existing studies, our estimated effect size is large. For example, we find a decrease in TFR of about 0.90% for each additional day above 30 degrees compared, whereas other studies varied between 0.85% and 0.18% for their highest temperature bin. There are at least two possible explanations for our larger effect size. First, this could be related to the higher threshold of the hottest temperature bin of >30°C. In fact, the coefficient for exposure to temperatures between 25-30°C shows to be closer to the one observed by Barreca et al. (2018) for days above 26.2°C. Second, our larger estimates could be related to the peculiarity of the Spanish context: a hot climate coupled with low AC coverage.

Table 2: Effect size comparison

| Study | Location | Heat (°C) | Outcome | Statistic | Results |
|---|---|---|---|---|---|
| This Study | Spain | >30°C (mean) | Birth rate | one-day (month) | - 0.90% |
| Cho (2020) | South Korea | 30–32°C (max) | Birth rate | one-day (month) | -0.24% |
| Barreca et al. (2018) | U.S.A. | >26.6°C (mean) | Birth rate | one-day (week) | -0.40% |
| Hajdu & Hajdu (2022) | Hungary | >25°C (mean) | Birth rate | one-day increase (week) | -0.18 to -0.85% |
| Thiede et al. (2022) | Sub-Saharan Africa | 1SD (mean) | Risk of birth | temperature (yearly) | -0.6% |

Note: in the table we compare the estimates of the impact of heat on fertility found in existing comparable studies. We show the largest estimates reported by these studies. Please note the different measures used by the other studies to capture the effect of temperature on fertility.

**Robustness and sensitivity analyses**

In this section, we show some supplementary analyses to test the sensitivity and robustness of our results. First, we use a relative measure of exposure to temperature. Recent climatic literature highlighted the importance of testing relative measures of temperature to consider location specific differences in susceptibility to temperature exposures (Cil & Kim, 2022). For that purpose, we create temperature bins based on the percentiles in the temperature distribution of each province in our period of analysis. The temperature bins are divided in days: < 1st percentile; 1st to 5th; 5th to 10th; 10th to 90th (comfort zone); 90th to 95th; 95th to 99th and > 99th. For example, the 99th percentile varies from 21.9°C in Asturias to 30.6°C in Sevilla. Results are similar to what we observed in the main analysis (Supplementary material: figureA3 and Figure 1), but the size of the coefficients appears smaller. Likely, this is due to some of the milder exposures captured considering temperatures above the 99th percentile.

Second, we used minimum temperature to estimate the exposure to tropical nights (i.e. days with minimum temperature > 20°C). In Figure A4 in the supplementary material, we observe that minimum temperature above 20°C decreases fertility but the effect size is smaller than what we observed in the main analysis with temperatures above 30°C. A similar pattern to the main analysis is observed when looking at the impact of tropical nights at different months from exposure (Supplementary material: Figure A5).

Third, we replicate the analysis in Figure 4 with an alternative measure of SES: the percentage of births from men with tertiary education (Supplementary material: FigureA6). We do not observe any substantive difference in the impact of temperature based on father's socioeconomic status at nine months or after. Likely, the results suggest that mother's socioeconomic status is more consequential than father's in driving a faster recuperation in births after exposure to heat. Finally, we run a placebo test by estimating the impact of the exposure to temperature 5 months after birth. Results in the Supplementary material in Figure A7 show null results substantiating our findings.

**Conclusion**

In this article we investigated the effect of temperature on fertility in Spain, a high-income country, with a fast warming climate, low fertility levels, and low AC penetration. We observed a detrimental effect of hot (>30°C) and warm (25-30°C) days on TFR. This result has a larger effect size than those found by studies on other contexts such as South Korea, United States and Hungary. This may be explained, as we argued, by the fact that Spain has a hot climate and a low coverage of AC, which imply that individuals may have a lower chance to mitigate the negative consequences of heat.

Our second main result is that, except across climatic areas, we do not find any heterogeneous effect of temperatures on fertility across population strata. The higher vulnerability to hot days in cold regions matches the findings of previous studies on fertility (Barreca et al., 2018), but also morbidity and mortality (Conte Keivabu, 2022; Medina-Ramon et al., 2006; Turner et al., 2012) and is expected as individuals living in colder climates may be less likely to be adapted to hot weather. We also observe highly educated mothers and older mothers to have more children ten- to-fifteen months after the exposure to heat compared to less educated and younger mothers. This result suggests a recuperation of the negative effect of heat on fertility for these socio-demographic groups, and it may reflect that both groups of mothers may prefer to recuperate the missed births faster due to their closeness to childbearing deadlines as well as it may reflect a preference in planned births.

Our study has some limitations. First, monthly rather than weekly data limits the temporal granularity of our analysis. For example, we are not able to disentangle specific mechanisms that could be related to spermatogenesis as done in previous studies (Barreca et al., 2018). Secondly, we are agnostic about the specific mechanisms that could explain the observed results. For example, we are not able to test if temperatures affect fertility impacting sexual activity or reproductive health. Thirdly, we are not able to test the mechanism that determine a stratified rebound in births based on the educational attainment and age of the mother. All these limitations should be addressed in further research.

In this study, we highlighted how temperatures influence fertility in Spain. This association will be likely exacerbated by future climate change, posing a threat to the already lowest-low fertility level in Spain, with the ultimate risk of further accelerating the ageing of an already old population.

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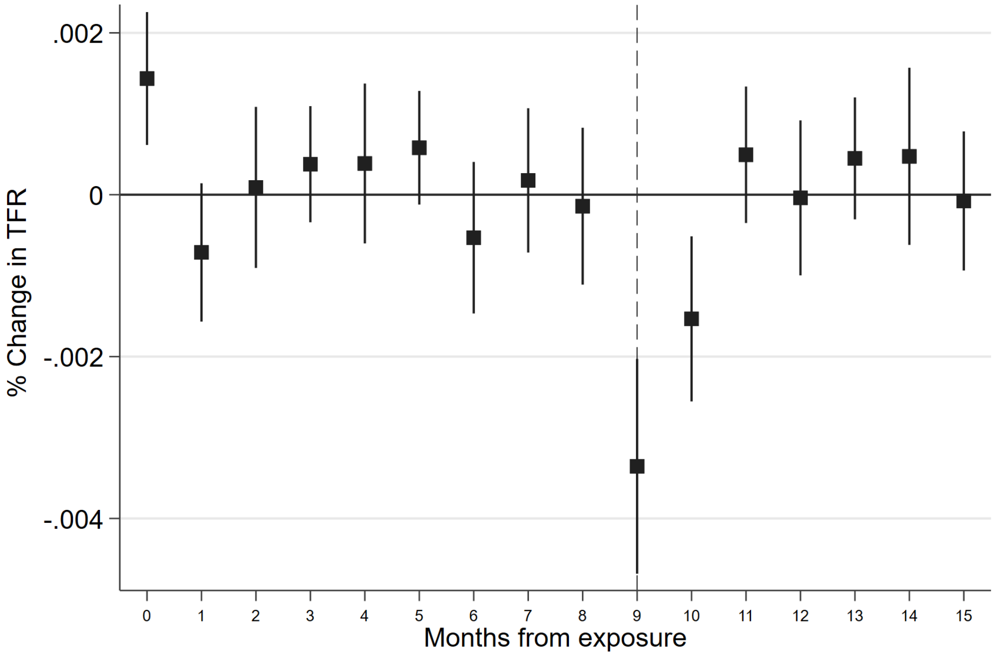
## Supplementary materials

Figure A1: Effect of days with mean temperature between 25-30°C on fertility at different months from exposure




Note: coefficients are estimated based on equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bin 25-30°C at different months from exposure. The other temperature bins are present in the model but not reported

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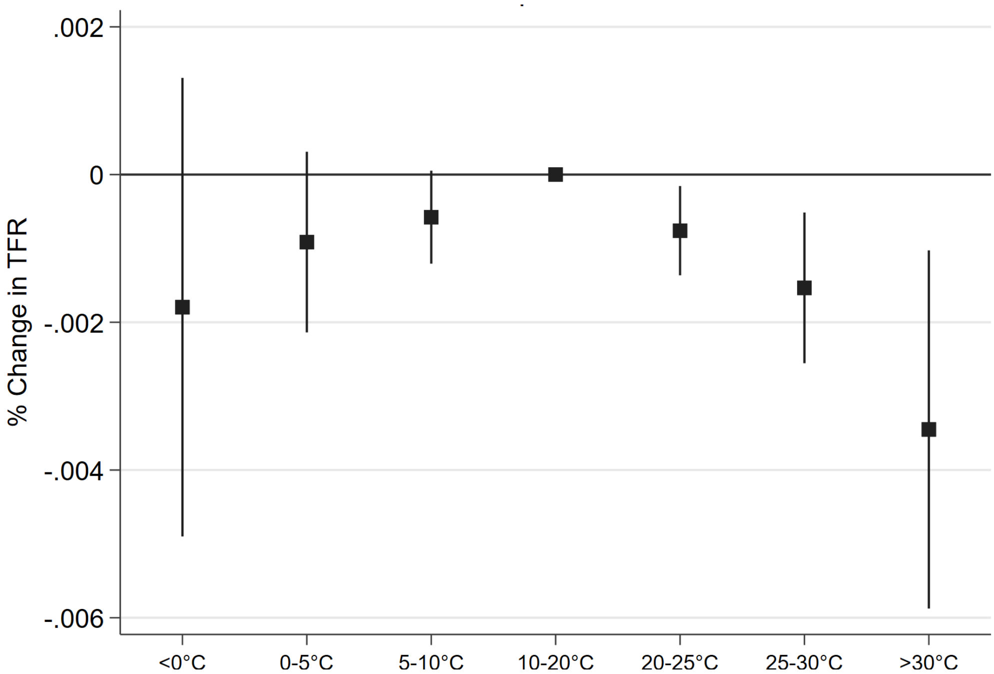
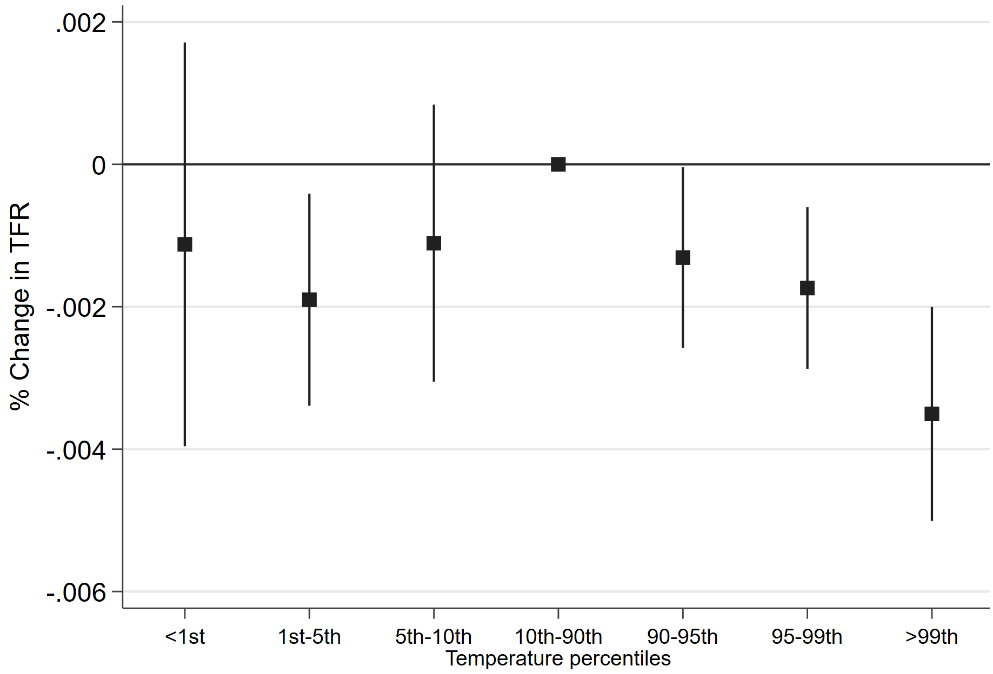
Figure A2: Effect of temperature on fertility 10 months after exposure.



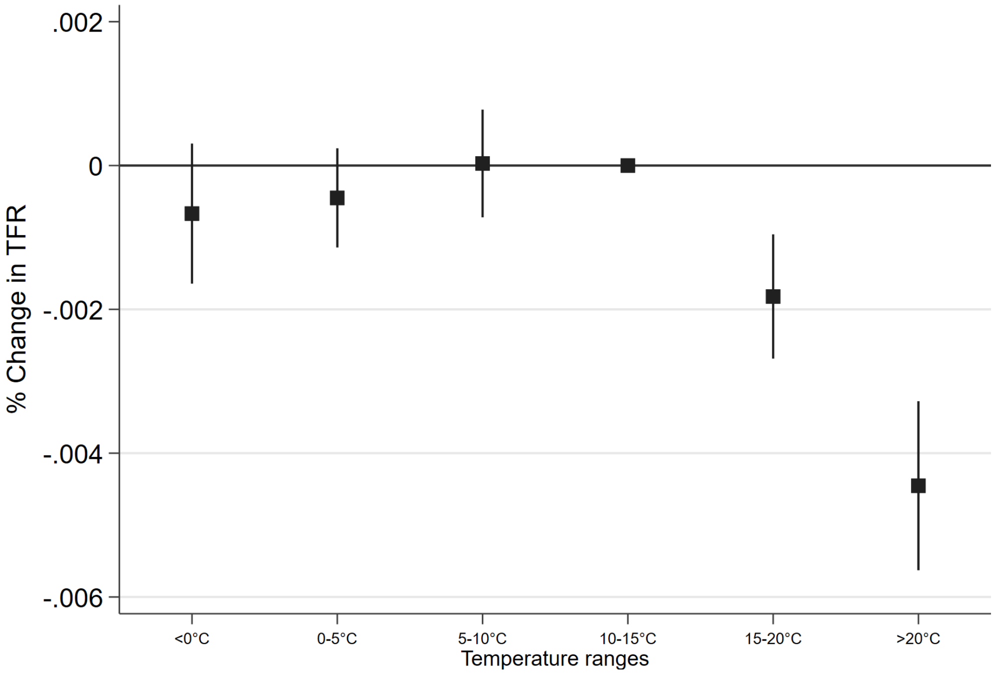

Note: coefficients are estimated based on equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bins at the 9th month from exposure. The temperature bins of exposure in the other months (0-9 & 11-15) are included in the analysis but not reported in figure.

Figure A3: Effect of relative temperature on fertility 9 months after exposure



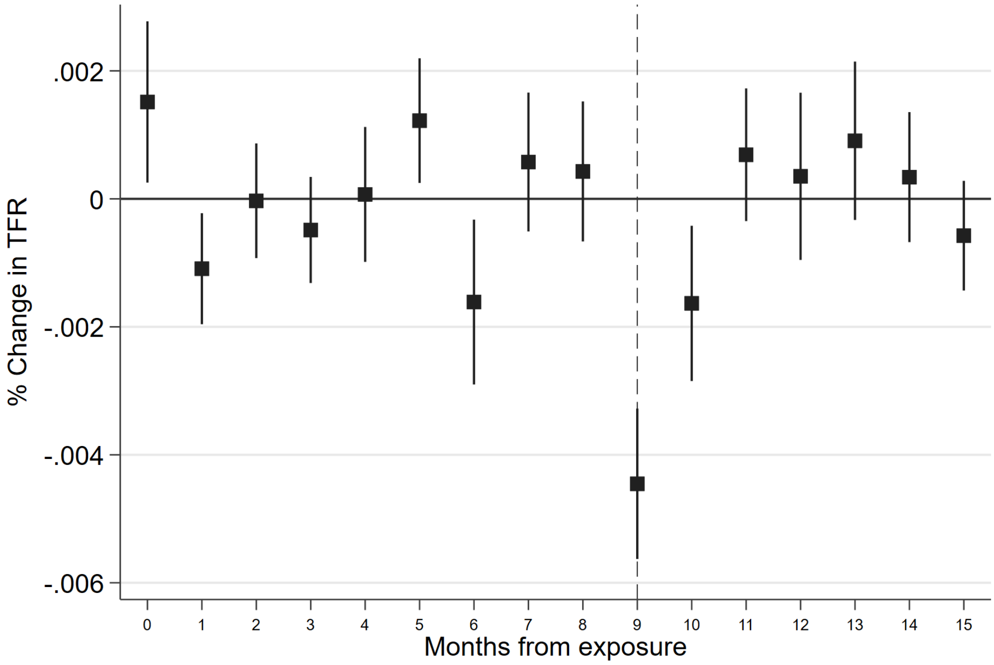

Note: coefficients are estimated based one equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bins based on percentiles computed using province specific temperature distributions. We show coefficients for the impact 9 months after exposure. The temperature bins of exposure in the other months (0-8 & 10-15) are included in the analysis but not reported in figure.

Figure A4: Effect of minimum temperature on fertility 9 months after exposure.




Note: coefficients are estimated based one equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bins based on the daily minimum temperature for the impact 9 months after exposure. The temperature bins of exposure in the other months (0-8 & 10-15) are included in the analysis but not reported in figure.

Figure A5: Effect of tropical nights, temperature > 20°C on fertility at different months from exposure.




Note: coefficients are estimated based one equation 1 with 95% confidence intervals. We report only the coefficients for the temperature bin >20°C based on the daily minimum temperature but include also the other temperature bins in the analysis. We show coefficients for the impact from 0 to 15 months after exposure

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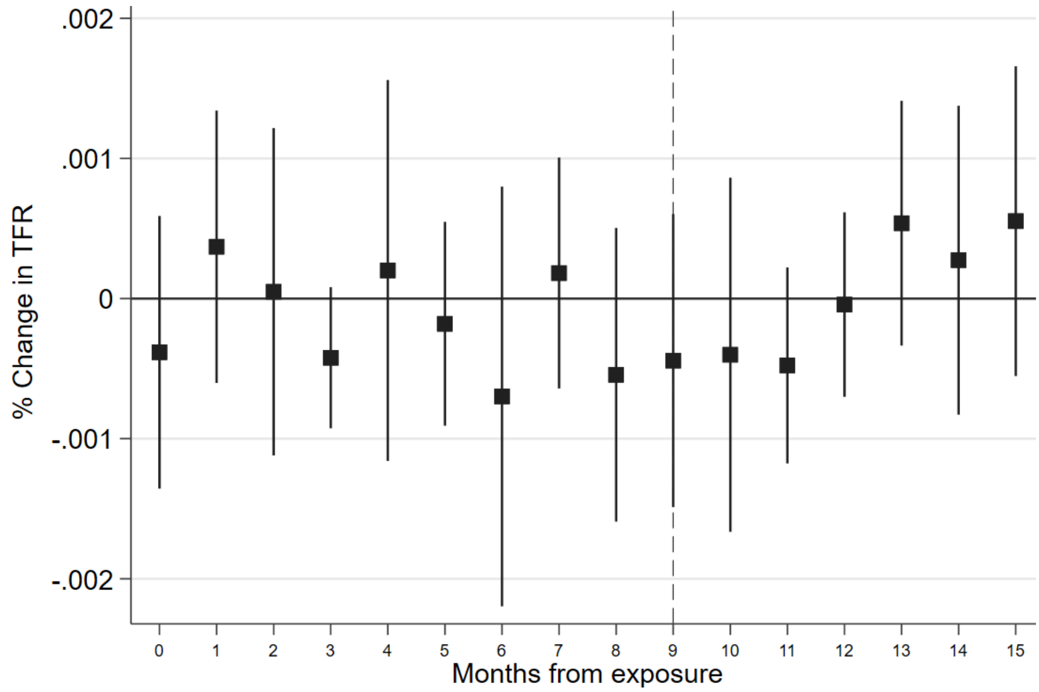
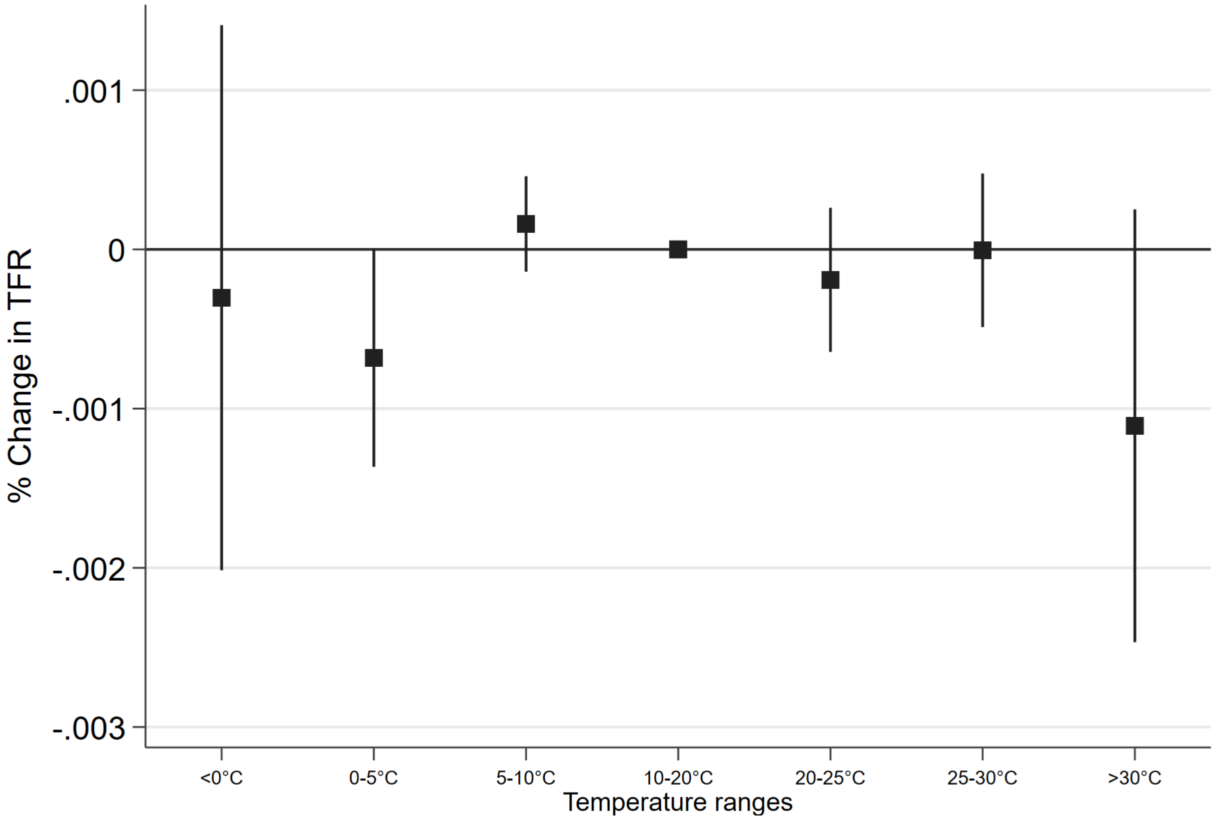
Figure A6: Days above 30°C and proportion of births for high SES fathers




Note: coefficients are estimated based on equation 1 with 95% confidence intervals and the proportion of births of father with tertiary education as our outcome. We show coefficients for the impact of days with temperature above 30°C with exposure from 0 to 15 months after, but we included also the other temperature bins in our analysis

Figure A7: Placebo test




Note: coefficients are estimated based one equation 1 with 95% confidence intervals. We show coefficients for the impact of temperature bins 5 months after birth.