The effect of temperature on fertility: A province-level analysis of monthly total fertility rates in Italy in 2003 – 2022

Melissa Barba*, Raya Muttarak*, Federica Querin*

Climate change-induced temperature increases and extreme weather events are impacting human health and wellbeing. Warmer temperatures are reported to affect both reproductive health and behaviors, possibly reducing birth rates. In a low fertility context, the potential negative impact that climate change might have on fertility is consequential. This study focuses on Italy, a low-fertility country disproportionately affected by climate change, with sharp regional disparities in both climate zones and economic development. Matching monthly birth registration data for the period 2003 to 2022 with E-OBS meteorological data, we analyze the relationship between heat exposure and total fertility rates in 107 Italian provinces (corresponding to the NUTS-3 classification). Results show that exposure to extremely hot days, which are defined as days with a mean temperature above 25°C, has a relatively immediate impact on conception probabilities as it reduces the total fertility rate nine months later. While this reduction is observed across both cold and hot climate zones, it appears to be stronger for warmer provinces. The effect of temperature on fertility also varies with the per capita gross domestic product (GDP), where fertility rates in the richest provinces appear to be more sensitive to warming temperatures. The interaction between climate zones and GDP per capita revealed that hot above-average GDP provinces are the most affected by rising temperatures.

Keywords: climate change, heat exposure, fertility, Italy

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Introduction

Recent evidence indicates that Europe is warming at more than twice the global average, with temperatures over European land areas reaching on average 2.4°C above the pre-industrial levels during the past five years (EUMETSAT 2025). This rapid warming has led to an increase in extreme weather events, including record-breaking heatwaves, persistent droughts, and flash floods, significantly impacting ecosystems, economies, and human health across the continent. Accordingly, in recent years, there has been growing interest in analyzing and understanding how changing environmental and climatic factors influence population dynamics under the context of climate change. Multiple studies have already explored the consequences of climate change and extreme temperatures on demographic outcomes such as mortality (Carleton et al., 2020; 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), and migration (Hoffmann et al., 2020, 2024). Apart from a few earlier studies focused primarily on the United States (Barreca et al., 2018; Lam & Miron, 1996; Seiver, 1985), it is only recently that research has begun to examine the climate effects on fertility and reproductive health more broadly. These include studies on South Korea (Cho, 2020), Hungary (Hajdu & Hajdu, 2022), Spain (Conte Keivabu, et al., 2024), France (Noel & Greulich, 2025) and 32 other European countries (Hajdu, 2024). These works consistently find a reduction in fertility from eight to ten months after exposure to extremely hot days.

This raises the question of whether this reduction in fertility following exposure to extreme heat also applies to Italy, a country characterized by marked regional variation in both climatic zones ranging from Alpine to Mediterranean, and economic conditions, with some of the widest subnational GDP disparities in Europe (Eurostat, 2023). Italy is among the countries in the Mediterranean area where climate change is accelerating most rapidly (Cramer et al., 2018; Perkins-Kirkpatrick & Lewis, 2020). Given its persistently low total fertility rates, coupled with evidence that climate change is impacting Italy more severely than many other European countries, Italy represents a uniquely important context for studying the potential impact of climate change on reproductive outcome. To the best of our knowledge, this is the first work focusing on the effect of rising temperatures on fertility in Italy. Using the administrative data on birth counts by Italian provinces from 2003 to 2022, we find that warmer temperatures, particularly daily mean temperatures exceeding 25°C, lead to a decrease in fertility rates, with noticeable effects nine months after the temperature spikes. Moreover, the drop in the total fertility rates after heat exposure is recorded for both cold and hot climate zones and is particularly larger for the latter. The effect of temperature on fertility also varies by the level of gross domestic product, with the richest regions being more sensitive to warming temperatures. The interaction between climate zones and GDP per capita further revealed that fertility decline after exposure to hot temperatures is particularly pronounced in the hot regions with GDP per capita above the national average. Our findings highlight the importance of considering geographical and socioeconomic variations on the effect of climate change on fertility outcomes.

This study contributes to the emerging field of climate change and fertility in three keyways. First, we provide new empirical evidence from Italy, a high-income country with persistently low fertility rates and evident regional climate variability. Using relatively fine-grained data at the NUTS-3 level over a 20-year period (2003–2022), our analysis confirms patterns previously observed in other European countries, such as the findings for Hungary (Hajdu & Hajdu, 2022), Spain (Conte Keivabu et al. 2024) and France (Noel & Greulich 2025). Second, we investigate how the relationship between temperature and fertility has evolved over time, assessing whether the effects have become more pronounced or shifted in recent years. Third, we explore regional heterogeneities by examining the interplay between geographical characteristics (i.e., climatic zones) and economic conditions (i.e., GDP per capita). This distinction is particularly important in the Italian context, where colder regions in the north are often also the wealthiest, making it challenging to isolate the separate effects of climate and socioeconomic conditions.

The remainder of the paper is structured as follows. The next section outlines the theoretical mechanisms through which climatic conditions may influence fertility. This is followed by a description of the Italian context. We then present the data and methods used in the analysis, followed by both descriptive and multivariate results. A series of sensitivity analyses and robustness checks are also included to assess the reliability of our findings. The final section discusses the results and concludes the paper.

Mechanisms linking climate conditions to fertility outcomes

Several pathways have been proposed to explain how climatic conditions, particularly extreme heat, can influence fertility. These mechanisms operate through biological, behavioral, and socioeconomic channels, each potentially contributing to short- and long-term changes in reproductive outcomes. With respect to physiological channel, previous studies proved that extreme temperatures have an impact on reproductive health because they affect both spermatogenesis (Hansen, 2009), sperm quality (Santi et al., 2016), and ovulation cycles (Gaskins et al., 2021), therefore reducing the probability of conception, gestational length (Barreca & Schaller, 2020), and the probability of carrying pregnancies to term (Rylander et al., 2013). Concerning the probability of successfully completing a pregnancy, extreme heat exposure might increase risk of spontaneous abortion in the first trimester, while in the weeks before delivery it might increases the risk of stillbirth (Kanner, 2020 and McElroy, 2022). Males are overall more affected by the negative consequences of heat on reproductive health (Barreca et al., 2018; Rojansky et al., 1992; Hansen, 2009). Heat exposure also has an impact on sex ratios at birth, resulting in a decrease in male births (Ghany et al., 2024).

Warmer temperatures, especially heatwaves and high humidity levels, are also correlated with poorer health in general, as they increase the probability of illnesses such as dizziness, heat strokes, influenza and exhaustion (Bai et al., 2014; Barreca & Shimshack, 2012). These temperature-induced diseases might impact fecundity and frequency of sexual intercourse, potentially affecting overall fertility. Contraceptive efficacy might also be negatively affected in relation to both high temperatures and prior health conditions. For example, hormonal birth control pills experience diminished effectiveness when stored at above room temperature (Barreca et al., 2018). The effectiveness of condoms also worsens at high temperatures (Gerofi & Sorensen 2016). The failure of contraceptive methods due to hot temperatures would lead to an increase in birth rates, potentially counterbalancing the negative effects due to physiological and behavioral factors.

Extreme temperatures can affect reproductive behaviors by reducing the frequency of sexual activity. This may occur due to discomfort, fatigue, or changes in daily routines and sexual desire, which can potentially decrease the likelihood of conception. Being a sensitive topic, empirical evidence on sexual behaviors is quite scarce and mixed: one study on sub-Saharan Africa reported that the number of sexually active women decreased with temperature (Wilde et al., 2017), while in Hungary no correlation was detected (Hajdu & Hajdu, 2019).

Recent scholarship is investigating the role of climate change concern – and more in general of environmental instability – on fertility outcomes by studying individuals' perceptions of and their implications on reproductive decisions. This approach permits us to consider how subjective believes shape fertility (Puglisi et al., 2025).

Seasonal patterns in births have been studied in demographic literature for over 50 years across various settings (Cowgill, 1966; Lam & Miron, 1991; Udry & Morris, 1967). Several studies have detected systematic differences in birth timing with planned pregnancies resulting in spring births. Historically, such timing may have been influenced by agricultural cycles: for instance, marriages and conceptions were frequently scheduled after harvest (Ellison, 2005). In contemporary industrialized contexts, seasonality in births tends to be shaped by sociocultural factors such as school enrollment cut-off dates (Dahlberg & Andersson, 2019), expectations about future economic security (Caleiro, 2010), or the timing of religious holidays (Friger et al., 2009; Herteliu et al., 2015; Polašek et al., 2005), along with the aforementioned environmental aspects.

Climate change may increasingly disrupt traditional seasonal patterns in births by altering the environmental and health conditions under which conceptions and pregnancies occur. Rising temperatures, extreme heat events, and deteriorating air quality—especially during summer months—have been associated with reduced conception rates and increased risks of adverse pregnancy outcomes, such as preterm births or fetal loss. These impacts may disincentivize conceptions during warmer periods, thereby shifting birth seasonality over time. Furthermore, climate-induced variability in agricultural productivity and economic uncertainty could affect household decision-making around family planning, particularly in settings still reliant on seasonal labor or income. Thus, climate change introduces new dimensions to the seasonality-fertility nexus, potentially reshaping reproductive behaviors in both high- and low-income settings.

Italian Context

The Italian average yearly temperature has increased by more than 1.5°C in the last 60 years, with a warming rate slightly stronger than the world average for the past four decades. In 2022, the temperature difference reached the highest spike of 1.9°C (Fig. 1). Temperature is increasing more quickly in high-altitude areas and during the spring and summer than in other seasons. Italy's average annual temperature is likely to keep surging, causing the number of hot days (daily maximum temperature above 25°C) and tropical nights (nighttime minimum temperature above 20°C) to increase. Although low and medium precipitation events have become less recurrent, the intensity of precipitation episodes per year has expanded all around the national territory.

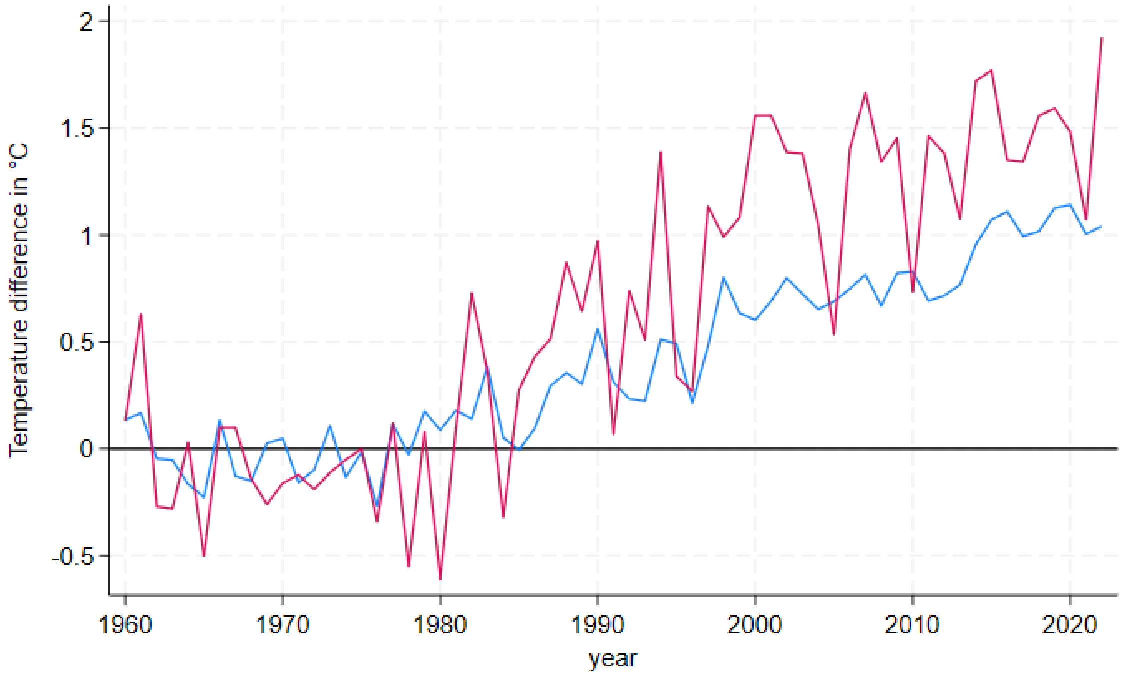

Fig. 1 Mean temperature annual differencess from 1960 to 2022. Reference period 1930 - 1960. Italian (red) and global (blue). Notes: data from Copernicus Data Store (2025)

Over the last two decades, Italian total fertility rates ranged from 1.29 children per woman in 2003 to 1.24 in 2022. Countries with a total fertility rate under 1.30 are classified as lowest-low fertility, and Italy, along with Spain, was the first European country to reach such level in the early nineties. Sustained low fertility leads to rapid population aging and reduced relative cohort sizes (Kohler et al., 2002). The territorial distribution of TFRs in 2022 is presented in Fig. 2. Total fertility rates above the national average are found in the North and in Sicily, particularly the 1.64 TFR recorded in the province of Bolzano was the highest value of 2022. Sardinian provinces and internal areas in the Center and in the South present instead the lowest fertility rates, with the lowest score of 2022 (0.88) reported in South Sardinia.

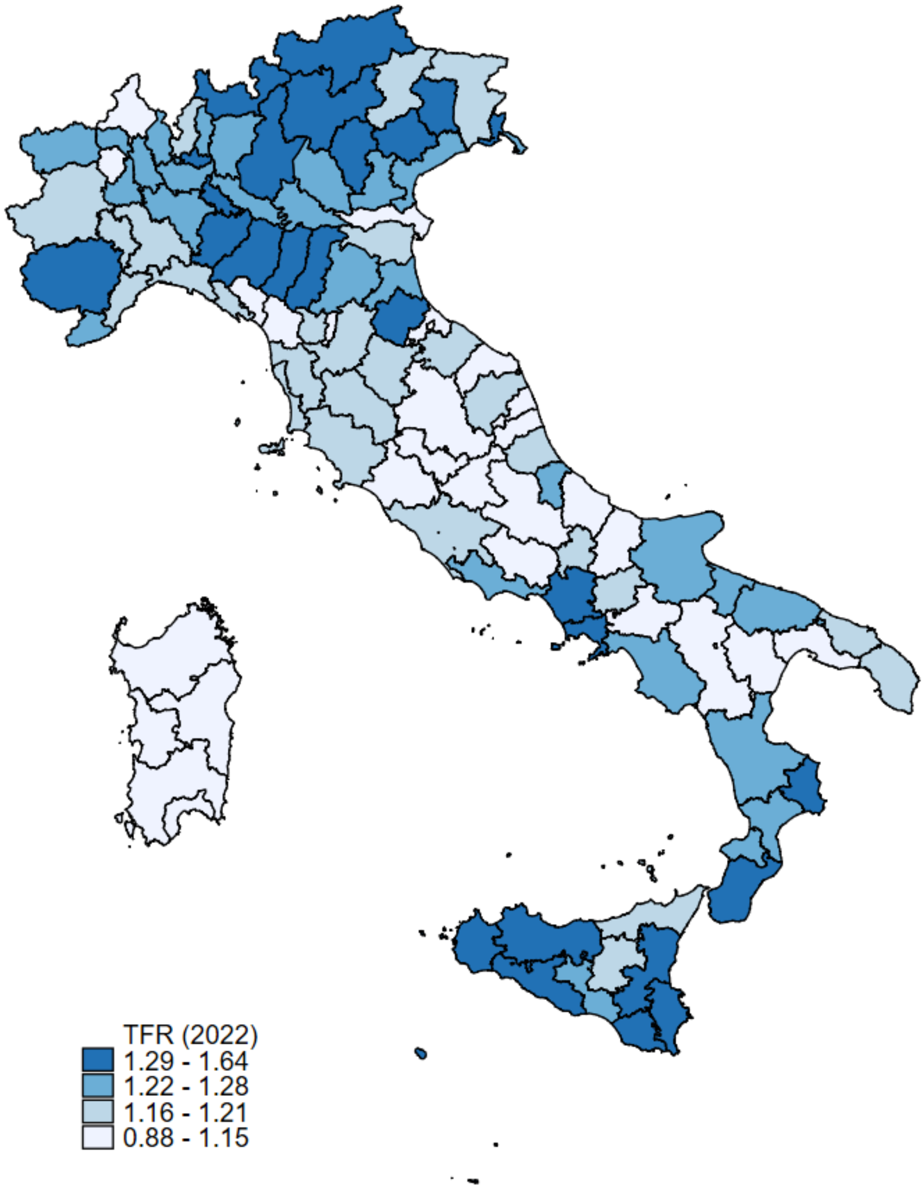

Fig. 2 Total Fertility Rate by province in 2022. Notes: data from ISTAT.

With a GDP per capita equal to 36,0720€ in 2023 (World Bank, 2025) Italy is considered as a high developed country. However, variations at the provincial level are pronounced: the lowest GDP per capita is recorded in Agrigento (14,872€) and the highest in Milan (53,109€). In general, Northern and Central provinces reveal higher GDP per capita than Southern and Islander provinces.

Data

This study analyzes the relationship between exposure to warm temperatures and fertility rates in 107 Italian provinces. The provincial administrative division corresponds to the NUTS3 classification. The total number of provinces changed throughout the selected period because new provinces were created while others were abolished. Comparability through the years is guaranteed using the current borders division (of 2023) as a benchmark for the entire time frame. The analysis spans from 2003 to 2022, ensuring a comprehensive assessment of trends over two decades. The starting year, 2003, was chosen as it marks a period with reliable and consistent data availability, while 2022 represents the most recent complete year of data. The study is conducted at the NUTS3 level, as going lower would present significant challenges. In small municipalities it is likely to find zero births in certain months, leading to unstable estimates and high year-to-year variability in total fertility rates. By working at the provincial level, we ensure statistical robustness while still capturing local differences effectively.

Fertility data

We combine two main sources of data: administrative data for fertility and GDP measures and E-OBS meteorological data for climate. We obtained administrative data from the Italian National Institute of Statistics (ISTAT), including the monthly number of births per women in each five-year age class in each province and the annual total number of women by age per province. As the total fertility rate is the sum of age-specific fertility rates, the first steps are getting the number of births per fertile women (conventionally aged between 15 and 49 years old) in each age class (in this case 5-years age class) and the total number of fertile women per age group. The number of women per age-group interval in each month was then obtained by linear interpolation. Combining monthly births by mother age group and number of women in each 5-year age interval we computed monthly total fertility rates (TFRs), which constitute our main outcome of interest.

Spanning across 2003 to 2022, monthly analysis is performed to capture the seasonality of the total fertility rate. The total sample of province-months is 25,680. The trend in fertility is shown in Figure A1 in the supplementary materials. After a slight initial increase in total fertility rates for the first year of the analysis, starting from 2012, total fertility rates are declining consistently. The graph also shows the seasonality of births: during warmer months, especially from July to October, TFRs are visibly higher than in the first months of the year, especially from February to April. The average seasonal peak of births is observed in July.

Climate data

E-OBS meteorological data with a resolution of 0.1-degree grid cells is collected by weather stations located all around Europe and is freely available in the Copernicus Climate Data Store (CDS). The analysis employs climate data on temperature, relative humidity, precipitation amount, surface shortwave downwelling radiation, vegetation extension, and air pollution. Meteorological data is weighted by population at the provincial level.

The temperature data is included at the daily level by constructing 7 temperature bins (0°C; 0 to 5°C; 5 to 10°C; 10 to 15°C; 15 to 20°C; 20 to 25°C; and > 25°C) and computing the number of days per month in which the daily mean temperature fell in each range for each province. Daily mean temperature accounts for both the daytime high and nighttime low temperatures, which act together upon various health risks. Bin classification addresses potential non-linearity of the effect of temperature on fertility at a given lagged month and avoids functional form specifications, since it is relatively nonparametric (Dell, 2014).

Relative humidity is a measure of how saturated the air is with water vapor compared with the total amount that can be held at a given temperature. Humidity aggravates the thermal stress experienced by people in extreme weather conditions because, at a given temperature, the higher the humidity, the lower the ability of the human body to cool itself by sweating, and the higher the risk of negative health consequences (Budd, 2008; Raymond et al., 2020). Considering the role of humidity in influencing the effect of heat on births may be important for a better understanding of the potential consequences of climate change (Hajdu, 2024). High-humidity days are defined as days with a relative humidity above 75%.

Precipitation occurs when a portion of the atmosphere becomes saturated with water vapor reaching 100% relative humidity, so that the water condenses and falls. In the analysis, we also control for precipitation measured as the total millimeters of precipitation recorded in a province in a month.

Surface downwelling shortwave is the sum of direct and diffuse solar radiation on the surface. The atmosphere allows the heat from the Sun (short-wave radiation) to pass through to heat the Earth's surface, which then gives off heat (long-wave radiation). This heat is trapped by greenhouse gases, which radiate the heat back towards Earth. Solar radiation is connected to climate change because this process ends up heating the Earth.

The vegetation measure used in this analysis is the Leaf Area Index (LAI), a common measure of plant canopy defined as the one-sided green leaf area per unit ground surface area. It depends on the size of the canopy, but also on its density, and the angle at which leaves are oriented in relation to one another and to light sources and it varies with seasonal changes in plant activity (Maass, 1995).

Air pollution is measured by Particulate Matter 2.5μg/m³ (PM2.5), which is widely used in studies on the negative impact of air quality on health (Colmer et al., 2020). Considering the combined effect of heat and air pollution is crucial because the atmospheric conditions that contribute to persistently hot weather also exacerbate air pollution. It is important to point out that a temperature rise due to air pollution occurs gradually and air pollution occurring in a certain month is not likely to affect temperature in the immediate future (Cho, 2020). However, there is evidence that elevated levels of air pollution such as PM 2.5, O_3, and NO_2 alters physiological processes in male and female fertility (Kumar & Singh, 2022 and Conforti et al., 2018).

The SPEI (Standardized Precipitation-Evapotranspiration Index) is a multi-scalar drought index based on climatic data that can be used for determining the onset, duration and magnitude of drought conditions with respect to normal conditions in a variety of natural and managed systems such as crops, ecosystems, rivers, and water resources (Vicente-Serrano et al., 2010). The Global SPEI database (SPEIbase) offers information about drought conditions at the global scale, with a 0.5 degrees spatial resolution and a monthly time resolution. The SPEI can measure the start and the end of drought episodes, as well as their severity through time and space. An important advantage of the SPEI over other drought indices is that its multi-scalar characteristics enable identification of different drought types and impacts in the context of climate change. SPEI was studied as an explanatory variable in the supplementary materials.

GDP data

Over the last decades, in many OECD countries fertility rates dropped significantly while the gross domestic product (GDP) continued to increase. The strong negative correlation between GDP per capita and fertility might not hold for high levels of per capita economic output, and the relation might turn positive from a certain threshold level of economic development. In several highly developed countries, total fertility rates have been growing since the early 2000s, along with continuing economic development, for example in France, the United States and Czech Republic (Luci-Greulich & Thévenon, 2014). Nordic countries, despite having relatively high fertility levels, large female labor market participation, and well-established family-support social policies, have experiences substantial fertility decline since 2010 (Campisi et al., 2022). The impact of economic growth on fertility is therefore ambiguous. The GDP per capita is obtained from Eurostat and computed as a mean over the period between

2013 and 2019, and the distribution is classified in quartiles. The lowest levels of GDP belong to the first quartile, while the highest are in the fourth quartile. The provinces with higher GDP per capita are also the ones presenting higher TFRs in general. GDP data is not included directly in the model, and the regression is run separately for all GDP quartiles.

Methodology

The study employs an OLS panel fixed effects model to analyze the relationship between temperature and fertility outcomes. The outline of the model is the following:

$$\ln[Y_{pt}] = \sum_{j}^{J} \sum_{k}^{K} \beta_k^j \, TEMP_{p,t-k}^j + \mathbf{X_{p,t-9}} + a_{pm} + \gamma_{py} + \delta_{pq} + \varepsilon_{pt}$$

where the outcome of interest is the logarithm of the monthly TFR in each province and month (Y_{pt}), and the main explanatory variable is the temperature categorized in bin variables and measured at the month of birth and up to fifteen months prior to conception ($TEMP^j_{p,t-k}$). The other meteorological control variables $X_{p,t-9}$ (relative humidity, precipitation amount, surface shortwave downwelling radiation, vegetation extension, and air pollution) are measured at the month of conception at the provincial unit. The model includes two fixed effects: province-by-year fixed effect (γ_{py}) and province-by-month fixed effect (α_{pm}) to capture province-specific factors and seasonality. The variable δ_{qm} represents the polynomial quadratic in the year-month of conception used to account for possible convergences in seasonality across provinces over time. The number of women of reproductive age in each province in the year before birth is used as a weight. Standard errors are clustered at the provincial level (ε_{pt}).

Results

Summary statistics

Table 1 reports the summary statistics for the monthly values at the provincial level of the variables of the analysis throughout the entire period. The province average monthly TFR of 0.11 reflects the lowest-low levels of yearly total fertility rates in Italy. Days with temperatures between 10°C and 15°C are the most common on average, while days exceeding 30°C are the least frequent.

Table 1 – Summary statistics

	Mean	SD	Min	Max
TFR	0.11	0.01	0.02	0.17

Births	392	462	28	4,773
Women in fertility age	123,326	135,883	15,083	968,143
<0°C	0.93	3.56	0	31
0 to 5°C	3.42	6.40	0	31
5 to 10°C	5.99	7.60	0	31
10 to 15°C	6.78	7.90	0	31
15 to 20°C	5.92	7.66	0	31
20 to 25°C	5.45	8.19	0	31
25 to 30°C	1.91	4.91	0	31
> 30°C	0.03	0.32	0	11
Relative Humidity	71.79	7.87	39.11	92.66
Precipitation	2.45	2.05	0	22.26
Solar radiation	159.40	77.54	23.09	407.30
LAI index	3.93	1.24	0.13	6.58
PM2.5	1.85	8.04	0.35	7.30
Population Density	265	370	35	2,6199

Notes: Summary statistics for the monthly values of the variables in our main analysis in the 107 Italian provinces in 2003 – 2022. Sources: ISTAT (demographic data), CDS (meteorological data)

The effect of temperature on fertility

Fig. 3 presents the effect of exposure to each temperature bin on the TFR nine months later with 95% confidence intervals. The effects are compared to a day with a mean temperature of 10-15°C. The temperature bins of exposure in other months are also included in the analysis but not reported in the figure. Warmer days have a negative effect on the total fertility rates, in particular the last temperature bin (>25°C) has the largest negative effect with a TFR drop by -0.31%, while colder days do not substantially alter fertility. This is coherent with previous studies (Barreca et al., 2018; Hajdu & Hajdu, 2022; Conte Keivabu et al., 2024). Other works (Barreca et al., 2018) showed that the effect of extreme temperatures is particularly strong also at the ten-month lag. Figure A2 in the supplementary material shows that there is a decrease in total fertility rates ten months after exposure to heat, though the effect is smaller than in the previous month (-0.15%).

Fig. 4 displays the effect on fertility of a day with a mean temperature above 25°C from zero to fifteen months after exposure. Although the model controls the full set of temperature bins, the figure shows the effects for the last one only, as Fig. 4 revealed that it is the one with a larger negative effect on fertility. The effects are compared to a day with a mean temperature of 10-15°C. There is a clear drop in TFR in month nine of -0.31%, confirming that a hot day has a relatively immediate impact on conception probabilities. Barreca et al. (2018) observed a positive increase in TFR in the months following the nine-month mark, which might be a signal of recuperation of the births averted because of the heat. Although this analysis does not detect such a significant positive trend, it shows that fertility declines around months 9 and 10 after exposure to high temperatures, with the downward trend tapering off thereafter. For temperatures exceeding 30°C (Fig. A3 in the supplementary material) there is an increase in total fertility rates from 11 to 15 months after heat exposure, but the coefficients are not significant.

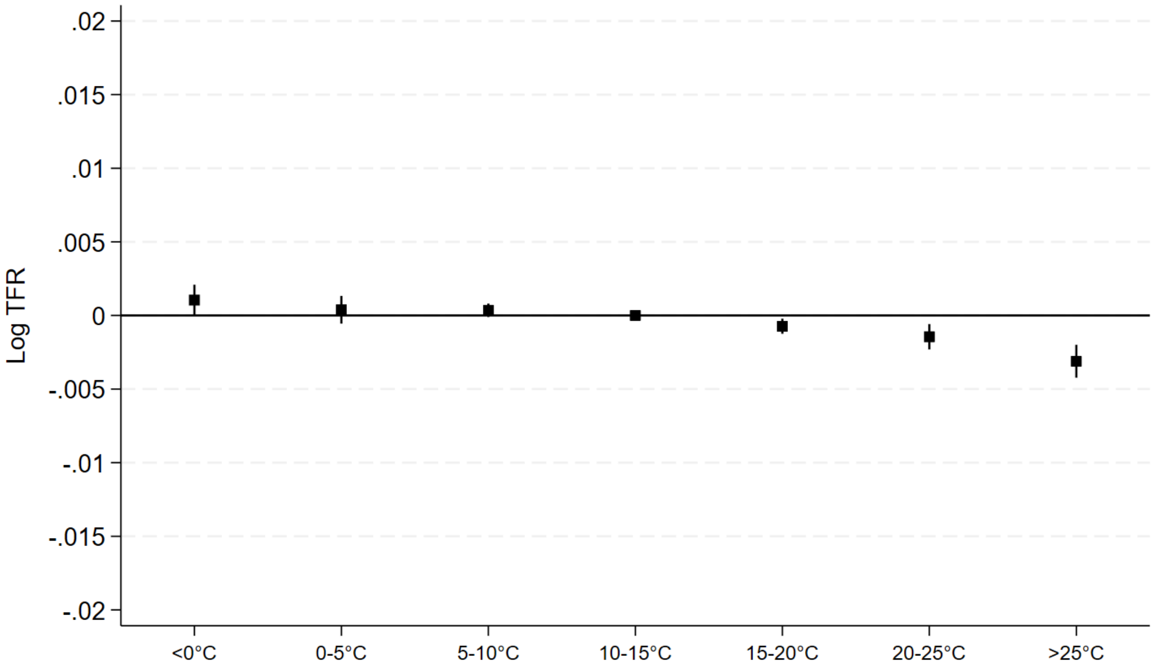

Fig. 3 Effect of mean temperature on fertility 9 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

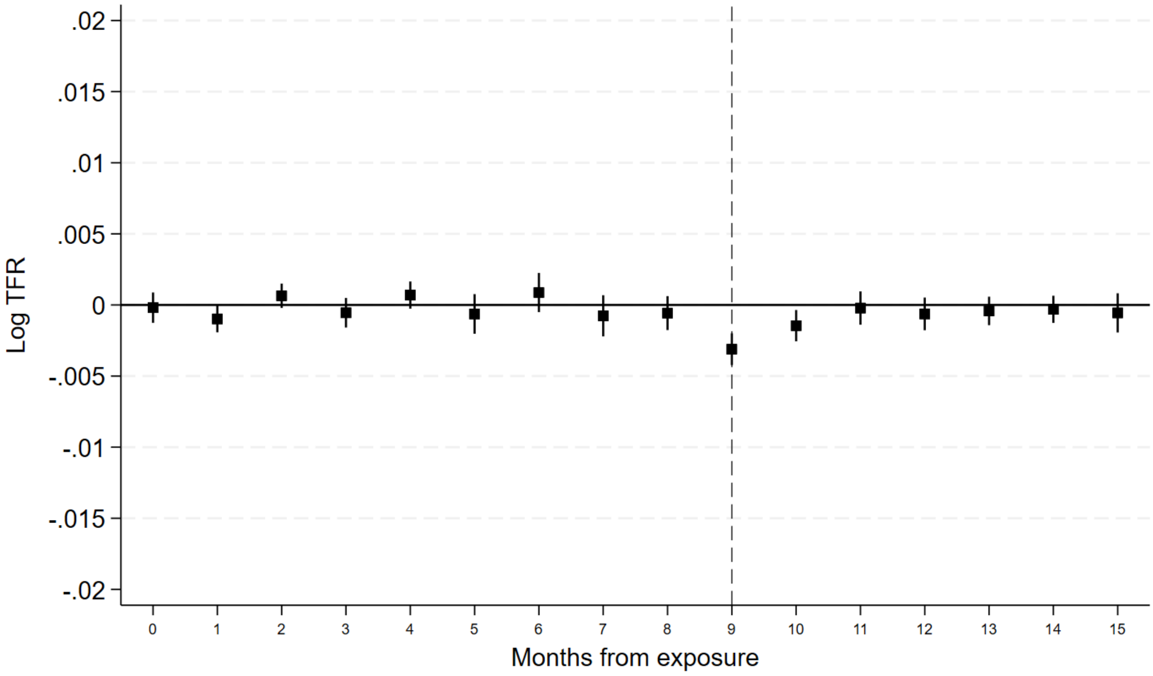

Fig. 4 Effect of a day with temperature >25°C on fertility from 0 to 15 months from exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure reports only the coefficients for the temperature bin >25°C at different months from exposure. Exposure to the other temperature bins is included in the analysis but not reported in the figure

The effect of temperature on fertility over time

The period of this analysis is long enough to explore whether the effect of temperature exposure on fertility has changed over the years. The time period is therefore divided into two equal groups: the first one going from 2003 to 2012, and the second one from 2013 to 2022. Previous findings show that the effect of temperature on fertility might decrease over time (Barreca, 2018) or remain stable (Hajdu, 2024). In the case of Italy, the effect size increased over the years. The coefficient for days above 25° C goes from –0.33% to –0.37%, while the coefficient for days between 20 and 25° C moves from –0.13% to –0.17%, as shown in Fig. 5. Due to the intensification of climate change over the years, the recent period includes more frequent and severe extreme-temperature events, which might have a larger impact on health and life planning, leading to more pronounced fertility decline. For the first period, negative temperatures are associated with a positive increase in fertility rate (0.22%), but this does not happen in the following years. Lower temperatures often correspond to winter months, which are historically associated with higher conception rates. This seasonal fertility pattern might have been more pronounced in the earlier period.

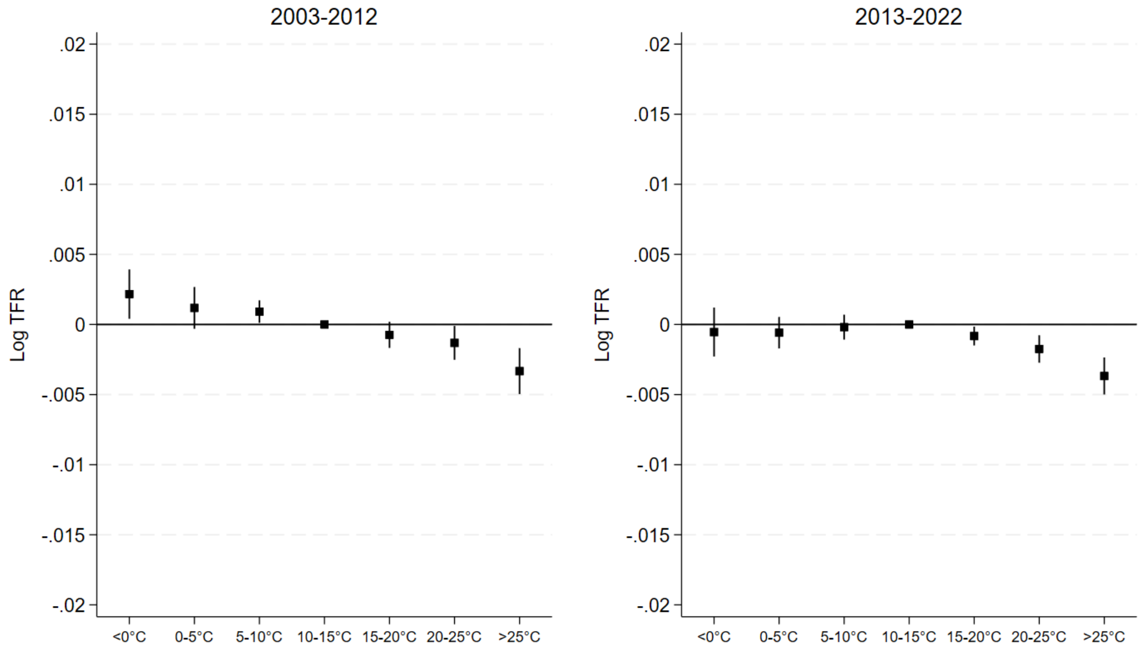

Fig. 5 Effect of mean temperature on fertility 9 months after exposure, by time periods. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

The effect of temperature on fertility by climate zones

The literature provides evidence that fertility rates in colder regions of a given country are more sensitive to heat shocks than warmer regions, probably due to lack of infrastructures and adaptation practices. Barreca et al. (2018) discovered that the effect of warmer days on fertility was larger in the colder climatic zones of the United States and Conte Keivabu et al. (2024) found the same effect in Spanish provinces. In this section, we explore how the relationship between temperature and fertility varies with climatic conditions by classifying Italian provinces into hot and cold zones, according to whether the province is above or below the median temperature in the sample. Cold provinces are mostly located in the North and in internal areas, while hot provinces are mostly on islands and coastal areas.

Fig. 6 replicates the analysis in Fig.3 but distinguishes between the two climate zones. In contrast with previous studies, the graph reveals that the effect of temperatures above 25°C on fertility is stronger for hot climates (-0.35%) than for cold ones (-0.21%). This difference might be explained by the fact that colder provinces in the North are usually better equipped to cope with occasional heat through widespread access to healthcare and air conditioning, while hotter provinces in the South tend to have more fragile healthcare systems and less access to cooling infrastructures.

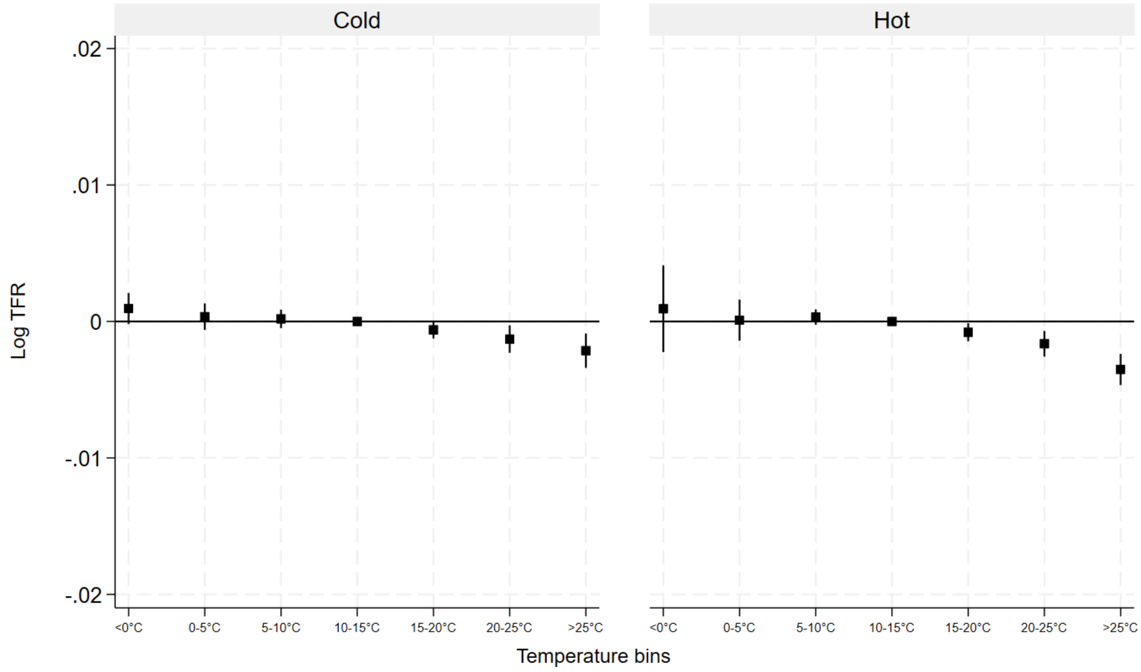

Fig. 6 Effect of temperature on fertility by climate zones. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

The effect of temperature on fertility by GDP

Looking at the effects of heat shocks on different levels of GDP, one might expect richer and more fertile provinces to be able to handle or to adapt to temperature extremes better. This is not the case for Italian provinces over the period of the analysis. Fig. 7 reveals that the poorest (1^{st} quartile) and the richest (4^{th} quartile) provinces are more affected by warmer temperatures, in particular the richest provinces are experiencing the largest contraction in total fertility rates (-0.41%). The drop in poorest provinces might be due to limited adaptation infrastructures, such as widespread air conditioning and public health services, and the largest proportion of outdoor labor, that might lead to a more disruptive effect of heat exposure at the physiological level. The decline in fertility in the richest provinces shows that wealthier areas also are affected by warming temperatures. In this case, exposure to hot weather might reshape individual behaviors and intentions, resulting in pregnancy postponement and signaling greater responsiveness in fertility behavior to climate-related factors.

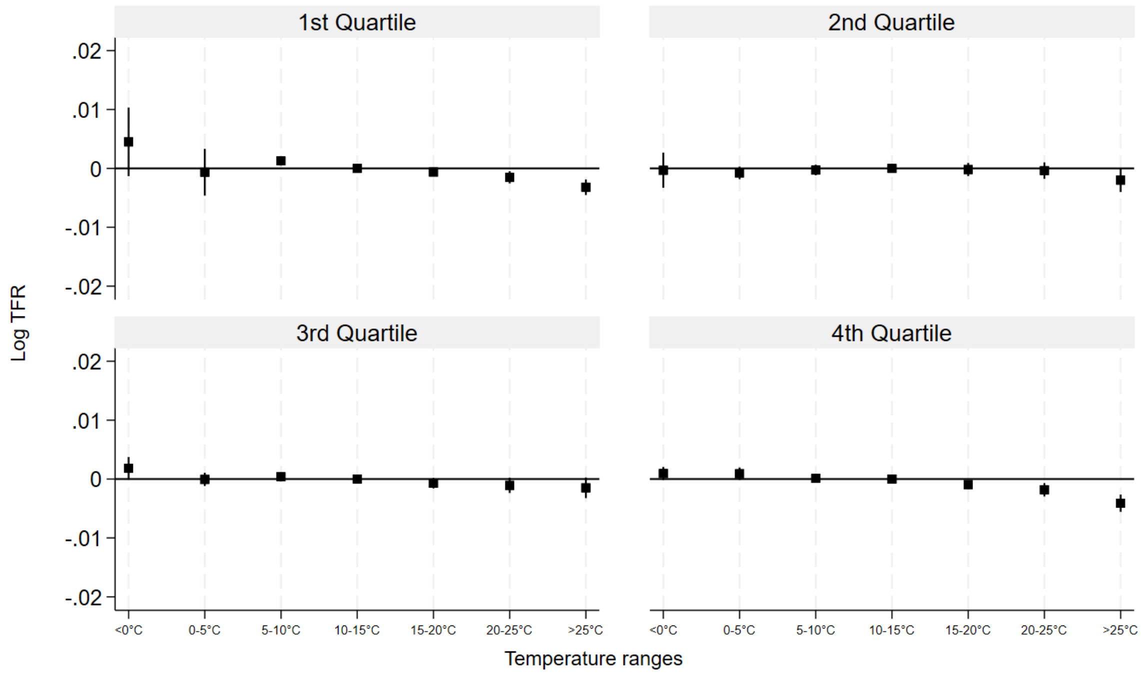

Fig. 7 Effect of temperature on fertility by GDP per capita quartiles. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

The interaction of climate zones and GDP on fertility

After examining the separate effects of climate zones and gross domestic product per capita on fertility, we extend the analysis to include their interaction. This step is crucial because climatic conditions and economic development are not evenly distributed across Italy and may exert overlapping or confounding influences on fertility. Colder regions are predominantly located in the northern part of the country, which is also the wealthiest. On the other hand, hot regions are mostly in the South and in the islands, which are generally less wealthy. As a result, it is difficult to disentangle whether the previously observed associations with fertility are driven by climatic factors, economic conditions, or both. Here we explicitly model the interaction between climate zones and GDP to better isolate the distinct and combined effects of environmental and socioeconomic contexts on fertility outcomes.

The per capita gross domestic product is sorted into two categories (above or below the national average), as the number of hot provinces in the fourth quartile of GDP distribution and the number of cold provinces with the first quartile of GDP is limited. Fig. 8 shows the effect on fertility of such interaction. The total fertility rate reveals a significant negative value for the highest temperature bin in each climate zone and for each level of GDP, except for cold provinces with a below-average GDP. The magnitude of this effect is notably stronger (-0.39%) in hot provinces with above-average GDP. The number of provinces with such characteristics is limited (14 out of 107) and most of them are in northern and central Italy. In the same way, the number of provinces with a cold climate and below-average GDP is limited to 15. Therefore, most provinces fall into the remaining two categories: cold provinces with an above-average GDP (39) and hot provinces with below-average GDP (39). This reflects the territoriality component of the variables.

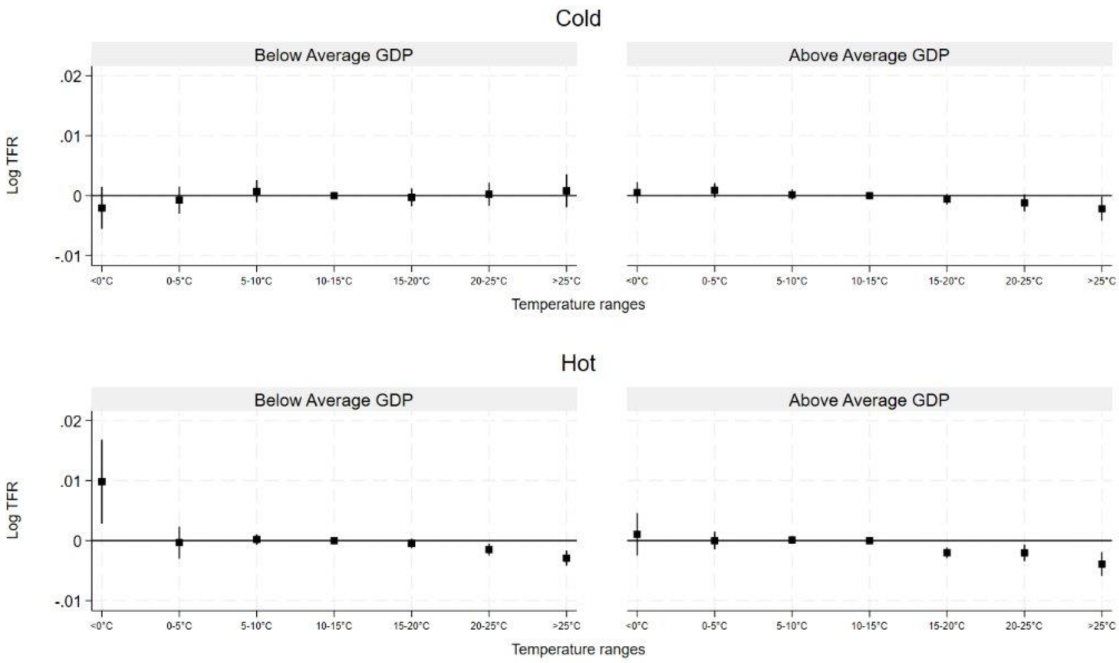

Fig. 8 Effect of the interaction of climate zones and GDP on fertility. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

Robustness and Sensitivity Analysis

Relative Temperatures

Climate literature stresses the importance of using relative measures of temperature along with absolute ones to capture substantial variation in average temperatures across regions that could generate different adaptation responses (Cil & Kim, 2022). This approach helps mitigate concerns about variations in climate within the provincial borders, as relative measures do not focus on specific temperature differences across areas.

Relative temperature bins are built based on the percentiles in the temperature distribution of the provinces. Temperature is therefore classified in seven categories: < 1st percentile, 1st to 5th, 5th to 10th, 10th to 90th (the comfort zone), 90th to 95th, 95th to 99th and > 99th. In this distribution, the 99th percentile includes values ranging from 9.06°C in Aosta to 28.85°C in Padova. Figures

A4 and A5 in the supplementary material reports present results that are coherent with the main analysis, but with smaller coefficients.

Temperature anomalies

Another way to measure relative temperatures is by estimating the long-term average and standardized anomaly considering a reference period. As the World Meteorological Organization (WMO) Policy established that the length of the baseline period should be 30 years, in this analysis the reference period spans from 1970 to 2000. Temperature anomaly is the difference of a temperature from the reference value, in this case the average of temperatures over the base period. Standardized anomalies are calculated by dividing anomalies by the climatological standard deviation removing the influences of dispersion. Figure A6 in the supplementary materials confirms that temperature anomalies, i.e. when temperatures get warmer than the reference period, result in a contraction in fertility rates at the ninth month with a coefficient slightly larger than the one observed in the main analysis.

The effect of SPEI on fertility

This analysis features the SPEI as an additional measure of climate change to study its effects on fertility. The SPEI index is calculated from 1 to 24 months in the past, to capture droughts from short to long periods. SPEI values are sorted into 5 categories to determine the severity: dry, moderately dry, normal, moderately wet, and wet. Figure A7 shows the effect of SPEI on fertility, although the results do not reveal a clear correlation between the two variables.

Discussion and Conclusion

This study analyzes the impact of temperature on fertility in Italy over a period of twenty years and discloses the adverse effect of warm days (with a mean daily temperature above 25°C) on monthly total fertility rates, while cold days do not affect fertility outcomes. The fall in fertility is recorded between 9 and 10 months after exposure, suggesting that heat both immediately reduces conception probabilities and causes some of the affected population to conceive in following months. The effect size of the exposure to each additional day with a temperature above the 25°C threshold is comparable to previous studies by Barreca (2018) and Cho (2020). The effect of the decline in fertility due to heat exposure translates into around 192 births lost for each additional day above 25°C in Italy over the period of the analysis.

The relationship between temperature and fertility is consistent across both climate zones: there is a drop in fertility for the highest temperature bin, and it is stronger in hot regions. The effect of temperature on fertility also varies in relation to GDP levels: the richest regions are more sensitive to rising temperatures, immediately followed by the poorest ones. Richer provinces are usually located in the North, and are exposed to colder temperatures, while poorer ones are situated in the South and in the Islands, where warmer temperatures prevail. The interaction between climate zones and GDP levels confirms that hot regions present a slightly larger contraction in fertility rates with respect to cold ones, and the adverse effect of temperature is more pronounced in above-average GDP provinces. The vulnerability to warm days in hot areas is unprecedented in literature and might be due to other socio-economic factors that prevent adaptation and mitigation of the adverse effects of heat.

This work has some limitations. Firstly, using monthly instead of weekly data reduces the accuracy of the analysis because it cannot unravel physiological mechanisms that might result in decreasing conception probabilities. Moreover, in this kind of analysis it is impossible to test behavioral mechanisms such as how temperature might affect sexual behaviors, which is an interesting avenue for future research. Using province level fertility data reduces the spatial granularity of the study as meteorological variables might vary within the provincial borders and considering mean values decreases the precision of the analysis.

This study complements the emerging research on the relationship between climate change and fertility providing new empirical evidence from Italy and confirms the trends observed in other countries around the world. Moreover, it is the first body of work that explores the regional heterogeneities of a country by interplaying geographical characteristics and economic conditions. This approach is essential in analyzing the Italian context, where isolating the separate effects of the two components becomes difficult, as the colder regions in the North are also the wealthiest and warmer regions in the South are also the poorest. This study has important policy consequences as the negative correlation between rising temperatures and fertility will likely be aggravated by climate change, threatening the rebound from lowest-low fertility levels and accelerating the ageing of an already old population.

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Supplementary materials

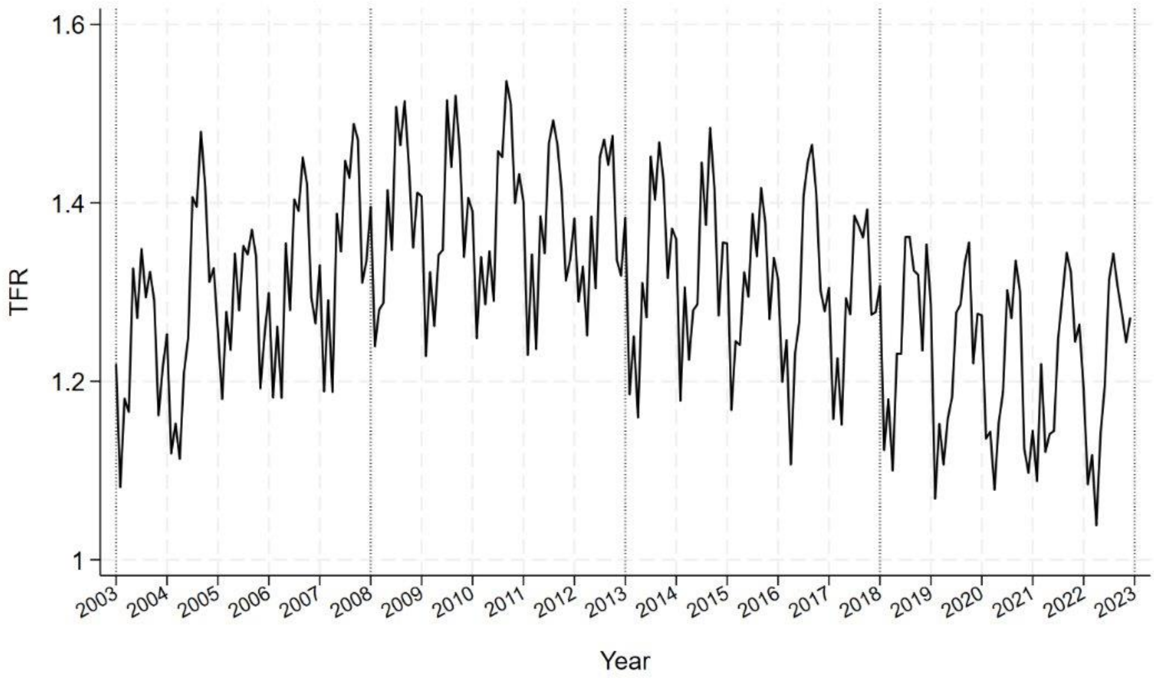

Fig. A1 Seasonal trends in Italian TFRs. Notes: monthly total fertility rates from January 2003 to December 2022

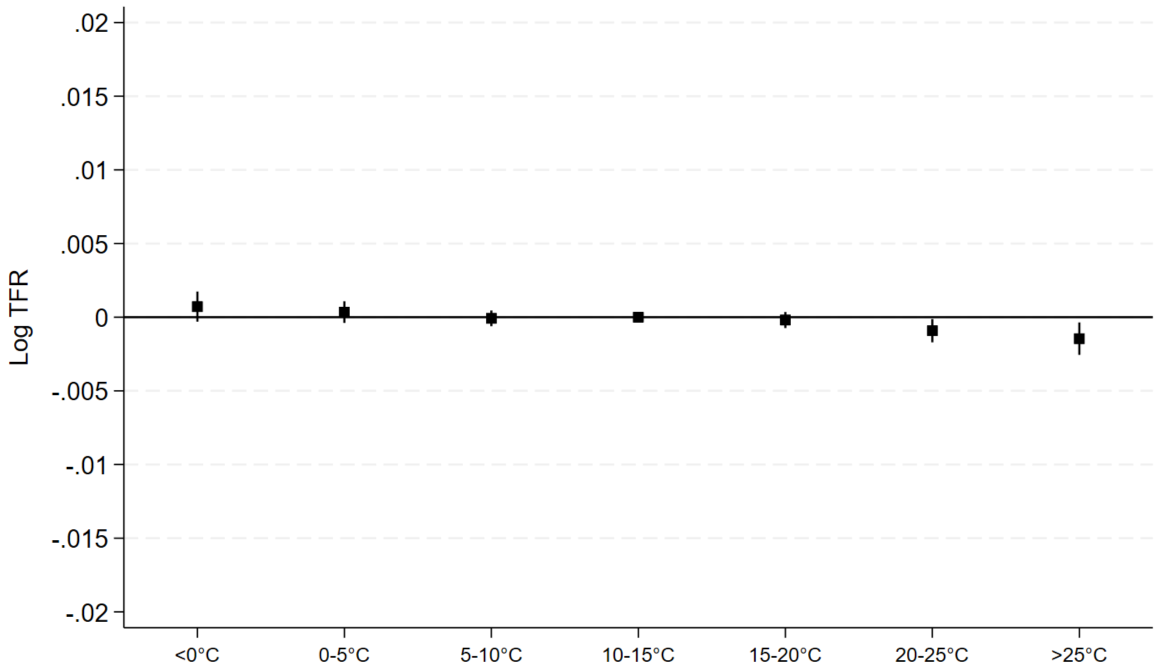

Fig. A2 Effect of temperature on fertility 10 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 10th month of exposure. The temperature bins of exposure in the other months (0-9 and 11-15) are included in the analysis but not reported in the figure

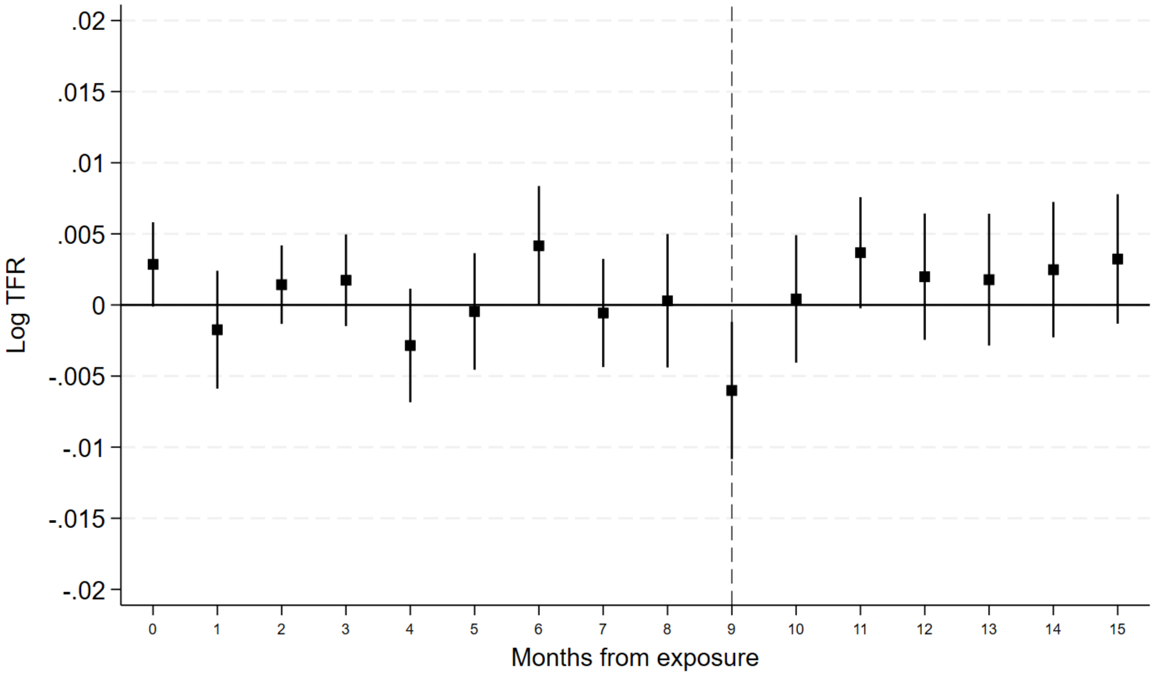

Fig. A3 Effect of a day with temperature >30°C on fertility 0 – 15 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure reports only the coefficients for the temperature bin >30°C at different months from exposure. Exposure to the other temperature bins is included in the analysis but not reported in the figure

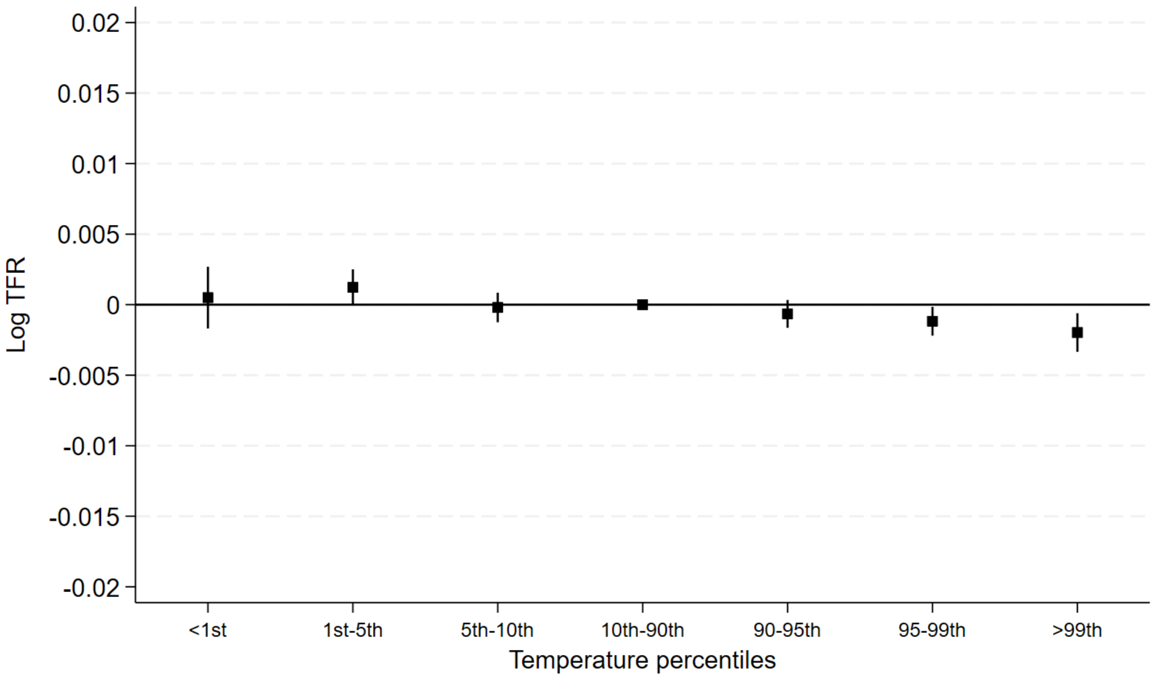

Fig. A4 Effect of temperature on fertility 9 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure

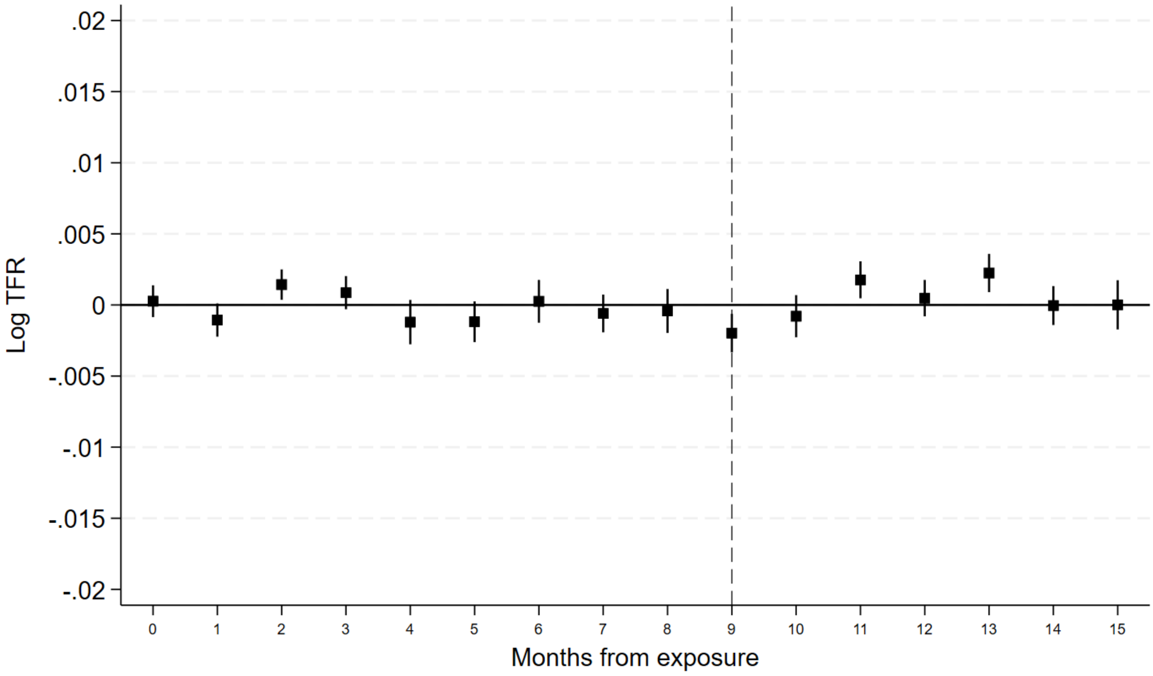

Fig. A5 Effect of 99th percentile temperature on fertility 0 – 15 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure reports only the coefficients for the 99th percentile at different months from exposure. Exposure to the other temperature bins is included in the analysis but not reported in the figure

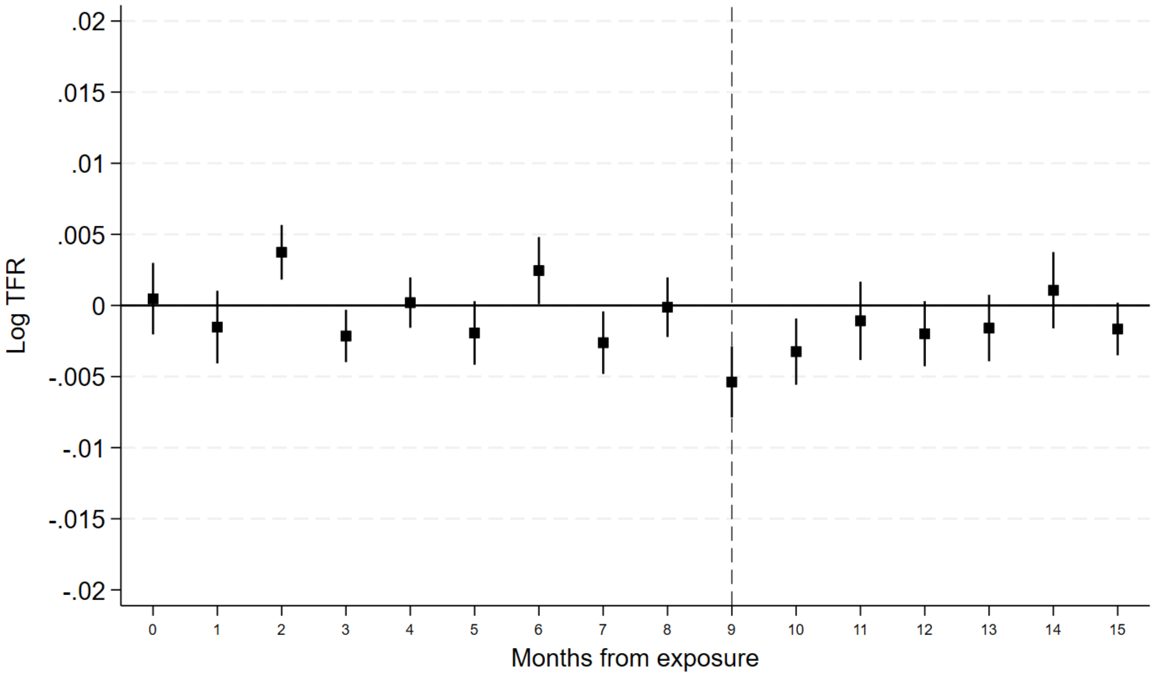

Fig. A6 Effect of temperature anomalies on fertility 0 – 15 months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows the impact of a one standard deviation in temperature

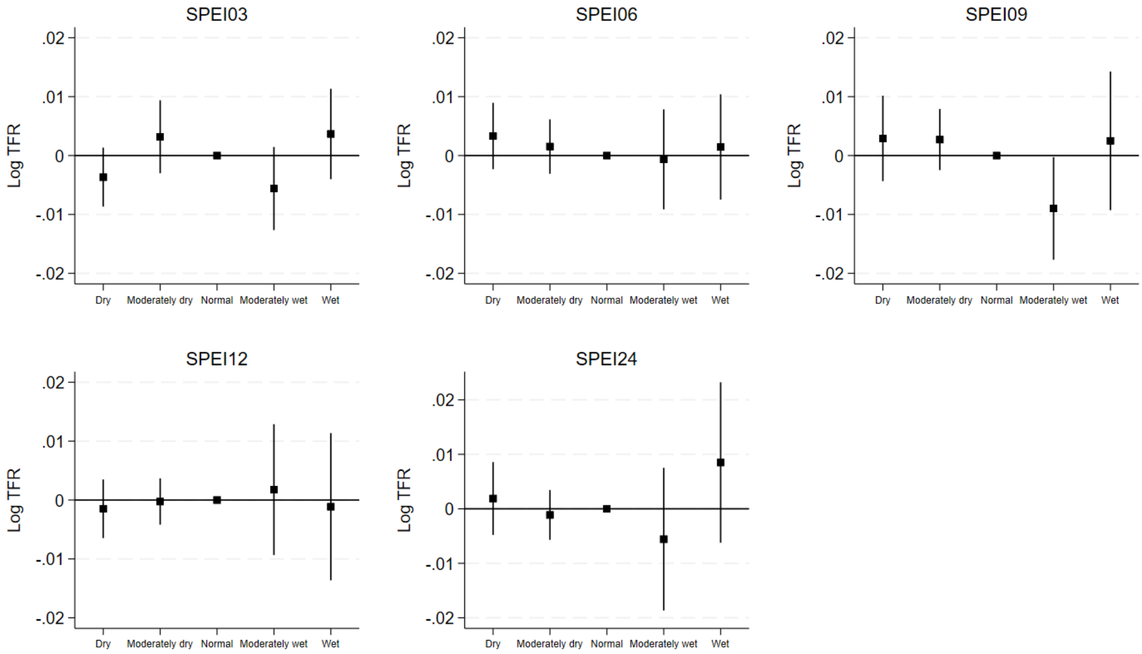

Fig. A7 Effect of SPEI on fertility nine months after exposure. Notes: coefficients are estimated based on equation (1) with 95% confidence intervals. The figure shows only the coefficients for the 9th month of exposure. The temperature bins of exposure in the other months (0-8 and 10-15) are included in the analysis but not reported in the figure.