The effect of climate on birth rates in Italian municipalities

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Abstract

We study the effects of climate conditions on birth rates in the Italian municipalities between 2003 and 2019. We find that days with a mean apparent temperature above 30^oC cause a significant decline in birth rates 9 to 10 months later, but this initial decline is followed by a partial rebound at month 12. Our estimates suggest that the temperature-fertility relationship has a tipping point at 25-30^oC, but at a lesser degree than above 30^oC. Precipitation and relative humidity do not affect natality rates. Heterogenous effects have been shown amongst municipalities. In particular, the highest cut in births, due to high temperatures, is documented for the biggest municipalities, where the phenomenon of the urban heat island is more pronounced, which in turn exhacerbates the climate effect.

Keywords: birth rates, climate, municipalities.

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1 Introduction

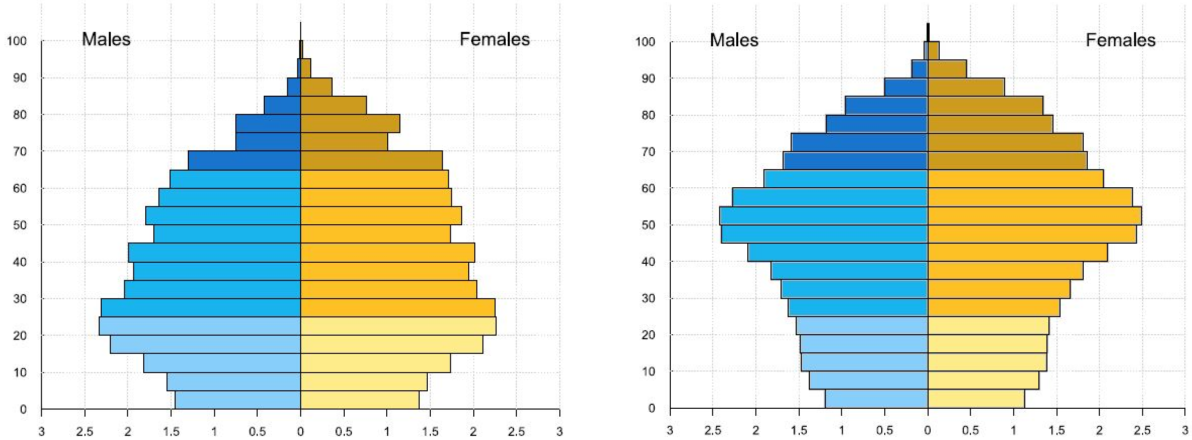
Over the last century, Italy has undergone a dramatic change in its demographic regime, moving towards a low fertility and low mortality scenario. At present, Italy shows very low levels of fertility while life expectancy figures are amongst the highest in the world. Accordingly, the share of working-age population over total population declined, leading to an increased weight of dependent population, especially the elderly. Moreover, shrinking child-bearing age female population anticipates even lower natality rates in the future. The striking change in the demographic behaviour of Italians has generally been ascribed to the rapid social progress and economic development that occurred in Italy after the end of the Second World War. Thus, the joint effect of decreased natality and increased longevity (see Figure 1) bespeaks a radical shift of the age structure of the Italian population. For this reason, aging causes many concerns in regards to economic growth, sustainability of health care and pension systems, and the well-being of elderly persons. Likewise, given that economic prosperity depends crucially on the size and quality of the workforce, many researchers postulate that the aging countries will experience slower economic growth. These potential and realized negative consequences of the gradual shift of the age structure towards the eldest shares of the population on economic growth, labor force participation and welfare state sustainability have been extensively documented.[1]

? examine the contribution of demography to economic growth in Italy since its unification. They find that changes in the age structure of the population gave a sizable positive contribution to economic growth in the past, but since the 1990s the contribution of demographic changes became negative, in spite of the partial offset due to migration; future projections suggest that demographic trends will continue to dampen economic growth. The paper shows that the negative effect produced by the evolution in the age structure could be effectively counteracted by developments which could be fostered by policy actions, such as longer working lives, increased female labor force participation, higher education levels. The effects of an increase in retirement age (as the one introduced in Italy by the Fornero reform in 2011) were studied, among others, by **?** (effects on workers and firm outcomes) and **?** (impact on labor force participation); **?** found that the evolution of the labor force participation in Italy was driven mainly by a rise in the share of individuals with high levels of education and increase in retirement age. In a recent work, **?**, instead, studied the potential consequences of the Covid-19 crisis on the demographic structure of the Italian population and consequently on GDP, over the period 2020-2065. Similarly to the climate crisis, the pandemic can impact natality via both biological and behavioral effects; if not countered by adequate policies, uncertainty and worsening economic conditions can influence fertility decisions as well as migration flows

[1] Among the main references, see**?**, **?**, **?**.

and accelerate the demographic decline of the population.

Figure 1: Italian population pyramids.



(a) 1990 **(b)** 2020

Source: United Nations, DESA.

The relationship between demography and climate received a huge amount of attention in recent years, due to the relevance of its social and economic implications and the high degree of uncertainty around future developments. The topic has been analyzed by academics, policy makers and international organizations from multiple perspectives, including the worsening of climate change do to overpopulation, climate change-induced migration and the impact of climate conditions on human health and mortality rates (see e.g. **?**, **?**, **?**, **?**, **?**).

A smaller stream of literature studied whether and how climate affects natality rates and fertility. In principle, climate and natality can be linked through a variety of channels, both direct and indirect, which can act differently according to geographical and socioeconomic characteristics.

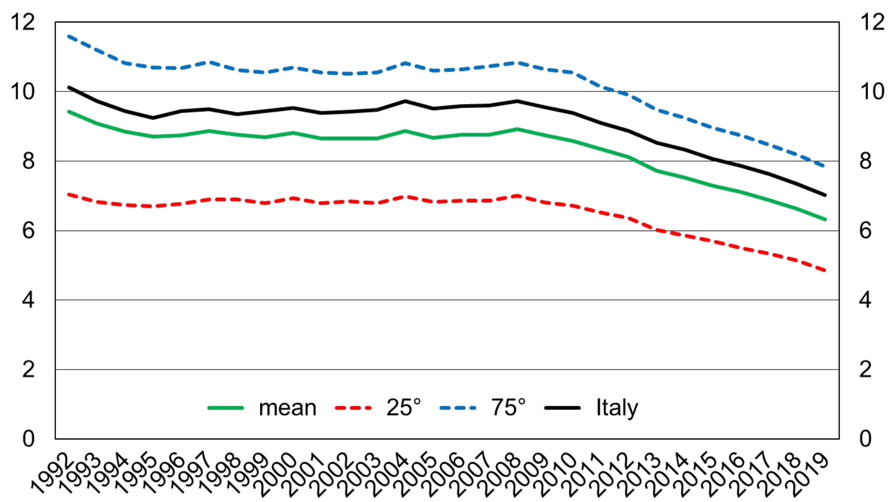
Among the direct links, growing temperatures and adverse weather conditions may affect reproductive health and pregnancy outcomes, via a biological effect.[2] Moreover, weather conditions may influence sexual behavior, although the little existing literature provides mixed evidence.[3] In addition, expectations about future climate can influence fertility decisions: an anticipation of the negative consequences of climate change (climate anxiety) and a high level of uncertainty may be factored into reproductive choices. In

[2]Several papers in the medical literature analyze the effect of climate on reproductive health and pregnancy outcomes, e.g. **?**, **?**, **?**, **?**. **?** conducted a systematic review of recent contributions on the effect of extreme temperatures on pregnancy outcomes. **?** looks at how studies of contemporary fertility transitions are better served when they include the impacts of climate change.

[3]**?** find no significant association using data about Hungary, whereas **?** find that sexual activity lowers with extremely high temperatures, using data from sub-Saharian countries.

the first large-scale investigation on climate anxiety in young people around the world, **?** find that the forty percent of the sample declare to be hesitant to have children due to the climate crisis.[4] **?** analyze a wide range of economic channels through which climate change might impact fertility, including sectoral reallocation and the gender wage gap, with heterogeneous effects at different latitudes. Extreme weather events and natural disasters can also trigger shocks to fertility, as studied by **?**, **?** and **?**.

Figure 2: Natality rates in Italy. Black line: annual crude birth rate (live-born births per 1,000 population) for Italy.



Notes: green line: mean birth rate for the 7,914 Italian municipalities, following Istat 2019 classification; red and blue lines: 25° and 75° percentiles of the distribution of birth rates among municipalities.
Source: our elaboration on Istat data

Within this strand of the literature, the present empirical work aims to fill the gap by empirically investigating the relationship of climatic factors on birth rates for Italy. Our analysis looks at the overall outcome of fertility decisions and biological factors, i.e. the number of births per 1,000 population, in a country with a high degree of heterogeneity in weather conditions. Using data at the municipality level, we can control for local characteristics on a very fine scale and exploit the variability in climate and demographic variables (see Section2). Our research design is similar to the one used by **?**, who estimate the effect of temperature shocks on birth rates in the United States between 1931 and 2010. In this paper, it is shown that extremely hot weather is associated with a sizable decline in birth rates 8 to 10 months later; in addition, results suggest that the initial decline is

[4] Previous results, based on smaller surveys, point in the same direction (**?**). In another paper **?** analyze the relationship between climatic variability and fertility goals among reproductive-aged women in Sub-Saharan countries and find that women exposed to unusually high temperatures, usually associated with poor agricultural and economic outcomes, tended to report a lower ideal family size and be less likely to want another child, relative to women exposed to average conditions.

followed by a partial rebound in births over the next few months, implying a dynamic adaptation via conception postponement. Taking into account an extremely long period of time, which includes decades where the age structure of the population and socio-economic conditions were profoundly different from present-day ones, findings can be compared to ours only partially. Moreover, the analysis in **?** uses as geographical units the fifty states forming the United States, hence weather conditions are averaged on quite an extensive area; in our study we rely on a much finer dimension (Italian municipalites), putting the spotlight on spatial heterogeneity. Although some limitations in our data, namely we cover the meteorological conditions only for a shorter period (i.e. 2003-2019), we add to the literature evidence on the temperature-fertility response relationship at the most detailed administrative level, such as municipality ones. Compared to several contributions, as previously stated, we can entirely exploit the heterogeneity of demographic and climate factors, thus better investigating the effect of extreme temperature conditions on birth rates. Our estimates indicate that hot weather causes a significant decline in birth rates 9 to 10 months later. One additional *hot day* with a mean temperature[5] above 30^oC relative to one day between 15-20^oC causes a decrease of 0.20% nine months later and 0.12% ten months later. After the initial decline, births rates partially rebound at month 12 offsets approximately 59% of the decline in births in months 9-10. These findings are also confirmed once used different temperature bins, suggesting that very high temperatures (i.e. above 32^oC) have a larger effect on reducing birth rates. Finally, we conduct further robustness checks to corroborate our results by splitting our sample into several groups, namely ecoregions, degree of urbanization, and altitude.

It is worth noting that the estimates of **?** work, and therefore ours, do not properly address the effects of climate change but more specifically the effects of variation of climate conditions in different areas. However, the former, covering 80 years of climate data, contributes to offer evidence that combines both the short-run and long-run effects of the different climatic conditions occurred over time. In our case, instead, we provide evidence for the Italian context about the relationship between climate and natality at large, but for overcoming this shortcoming and validating our results in a framework of climate change we will extend this empirical exercise over the period 1992-2019. In this manner, despite losing monthly information due to lack of natality data at this level, the expansion of the period covered by weather data allows to investigate climate change effects.

The remainder of the paper proceeds as follows: Section 2 introduces the data used and provides summary statistics. Section 3 introduces the empirical strategy applied. Results and robustness checks are discussed in Section 4 that precedes our conclusions in Section 5.

[5]Notice that hroughout the entire paper when we use temperature we always refer to apparent temperature (see Section 2.2.2 for the definition).

2 Data

2.1 Demographic indicators

We use data from the Italian National Institute of Statistics (Istat) to construct our demographic time series at the municipality level. Based on the available data at such granular spatial detail, we focus on crude birth rate (CBR) as our main indicator of natality. For a given area, the crude birth rate in period t is defined as the ratio between the number of live-born births in period t and the average population of that area in period t, multiplied by 1,000. Notice that, CBR, by definition, is a *crude* measure of natality, as it is affected by the demographic distribution of the population in the denominator, especially by sex and age. Nevertheless, CBR is a widely used indicator which is useful to compare population growth in different areas and across time. In our setting, moreover, monthly CBR is the indicator which allows to exploit at high frequency all the geographical and time heterogeneity of the weather data.

In particular, for each of the 7,914 Italian municipalities existing at the end of 2019, Istat data allows to construct the annual CBR over the period 1992 - 2019 (28 years). However, due to data limitations, monthly CBR is available for a shorter period, from 2003 to 2019 (204 months).

Furthermore, to get consistent time series, we adopted the Istat territorial classification in force at the end of 2019 (i.e. 7,914 municipalities), and we adjusted backwards the demographic data accounting for administrative changes occurred in the previous years, such as establishment of new units, extinction of formerly existing ones, changes of upper-level administrative unit, denomination variations.[6]

Clearly, an indicator that considers the composition of the population, for example the number of women in child-bearing age, should be a more accurate measure of the natality trends. In this respect, we can compute the annual time series of the general fertility rate (GFR) at the municipality level over the period 2002 to 2019 (18 years). GFR is defined as the ratio between the number of live-born births in a given year and the average number of women in child-bearing age in year t, times 1,000; conventionally, child-bearing age spans from 15 to 44 years.[7] Despite GFR being more precise, we lose monthly information both for natality rates and weather conditions, reducing the opportunity to control for

[6]See https://www.istat.it/it/archivio/6789 for all the details. In our analysis we did not account for territorial changes, e.g. changes in borders and transfer of part of a municipality to another one, due to lack of data.

[7]We do not use other demographic indicators such as Age Specific Fertility Rate (number of live births per 1,000 women of a specific age in a given period) and Total Fertility Rate (average number of children per woman that would be born to a cohort of women who experienced, throughout their childbearing years, the Age Specific Fertility Rate of the calendar year in question) since they are not available at the municipality level.

seasonality and further heterogeneity in these attributes. Consequently, we leave this sensitivity check to a subsequent extension of the present empirical exercise.[8] Our outcome of interest is the monthly log of the CBR over the period 2003-2019.

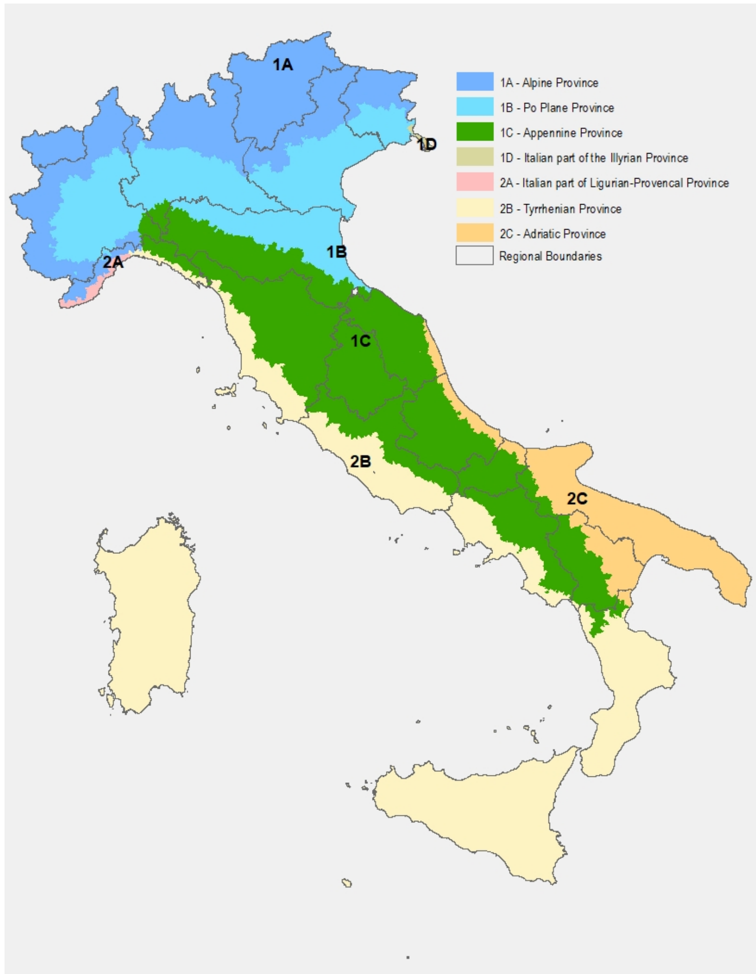
To dismiss the concern that the identifying variation in our model might be driven mainly from a select group of municipalities sharing homogenous characteristics, we also classify municipalities according to specific attributes as defined by Istat.[9] We focus on three criteria. First, we use a classification of municipalities based on the concept of ecoregions, or ecological regions, i.e. clusters of municipalities identified on the basis of homogeneity with respect to climatic, biogeographical, physiographic and hydrographic factors.[10] The ecoregions are portions of ecologically homogeneous territory in which the physical features of the environment influence the presence and distribution of species, communities and ecosystems; hence, this classification of municipalities is a natural setting to study the relationship between demographic factors and portions of territory with common features in terms of climate or bio-geography. This approach can provide some useful insights into the heterogeneity of the relationship between climate and natality, which could be lost using administrative classifications of municipalities such as regions or macroareas. Istat allocation of municipalities into ecoregions offers a hierarchical classification with four layers and increasing degree of homogeneity; the partitions include, respectively, 2, 7, 14 or 35 divisions. In our analysis we focus on the 7-province classification (1A - Alpine, 1B - Po Valley, 1C - Apennine, 1D - Italian part of the Illyrian, 2A - Italian part of Ligurian-Provencal, 2B - Tyrrhenian, 2C - Adriatic (see Figure 3).

[8]Similarly, as an additional robustness check, we will also extend the empirical analysis about the effect of climate conditions on yearly CBR over the period 1992 - 2019

[9]See for additional details about these classifications the following website: https://www.istat.it/it/archivio/156224

[10]See https://www.istat.it/en/archivio/224797 for the details. Notice that in the international context this ecological classification of territories into ecoeregions is usually adopted as tool to defined strategies of sustainable development and territorial management at different level.

Figure 3: Italian ecoregions.



Source: Istat

Second, municipalities are grouped according to three levels of urbanization. The categories are defined as follows:

- city or densely populated areas,
- small city, suburbs or intermediate-density areas,
- rural areas or sparsely populated areas.

Third, municipalities are clustered by considering their altitude as follows:

- internal mountains,
- coastal mountains,
- inner hill,

- coastal hill,
- valley.

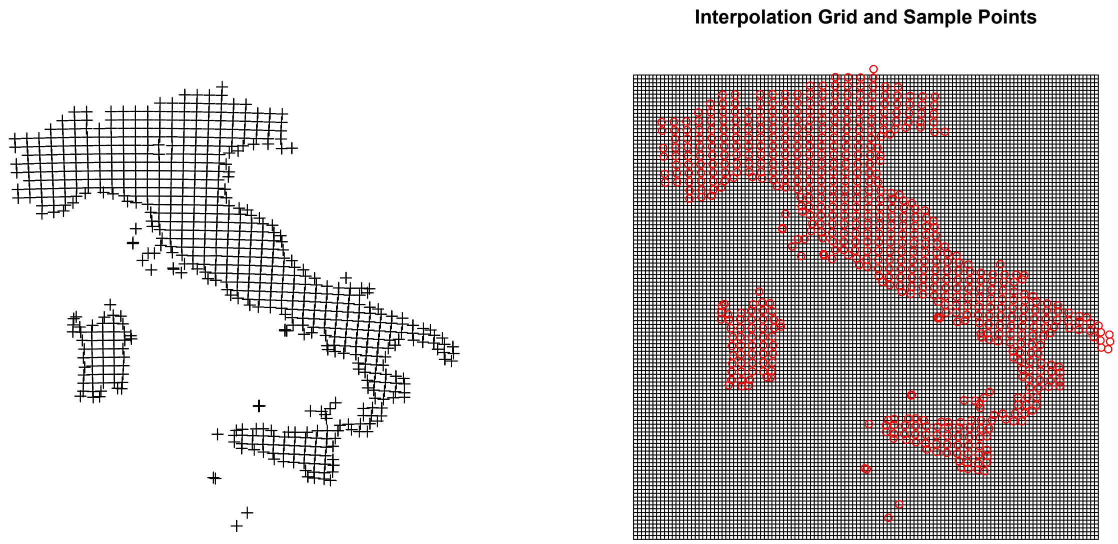
2.2 Meteorological data and interpolation

The meteorological dataset used for this analysis is AGRI4CAST (**?**), which is provided by the JRC MARS Meteorological Database and contains observations from weather stations interpolated on a 25X25 km^2 grid (Figure 4a), on a daily basis from 1979 to the last calendar year completed, for the European Union and neighbouring countries. It includes the following variables:

- maximum and minimum air temperature (^oC),
- mean air temperature (^oC)
- mean daily wind speed at 10m ($m\ s^{-1}$)
- vapour pressure (hPa)
- precipitation ($mm\ day^{-1}$)
- potential evapotranspiration from a crop canopy, ($mm\ day^{-1}$),
- total global radiation ($KJ\ m^{-2}\ day^{-1}$).

In order to match the municipality boundaries and the meteorological data we need a finer grid (Figure 4b), since the area covered by the municipalities is, in many cases, smaller than the grid size. We chose a resolution of lon-lat equal to $0.025^o X 0.025^o$. As a matter of fact, this resolution guarantees that we have at least on point of the grid for each municipality. In the case we found more than one grid points within the municipality boundaries, we take the average of them as the value to be attributed to the specific municipality. Figure 4b shows an example of the finer grid but, for clarity of the graphic appearance of the figure, at lower resolution respect to the one we use.

Figure 4: Data interpolation grids



(a) Original grid

(b) Interpolation and original (red) grids

2.2.1 Climate explanatory variables

2.2.2 Apparent temperature

Concerning the temperature, we employ the average apparent temperature (AT) index proposed by **?** that considers all environmental and body conditions that affect human thermoregulation.

$$AT[^oC] = -2.7 + 1.04T + 0.2e - 0.65v$$

where T [^oC] is the air average temperature, e [hPa] the vapour pressure and v [ms^{-1}] the wind speed.

The distribution of daily average AT (in Celsius degrees) is defined in bins using the interval distribution of the physiological discomfort thresholds suggested in the guideline of ARPA Piemonte (Regional Environmental Agency). The ARPA bins are as follows:

- AT $<$ 27 ^oC Wellness
- 27 $\leq$ AT $<$ 32^oC Caution
- AT $>$ 32 ^oC Extreme caution -Danger - High danger

In addition, with reference to the bins suggested by ARPA, we collapse the highest three intervals in only one, since we have no observations within such high values. Finally, in order to disentangle the effects of very low, low and medium average AT we split the temperature below 27 ^oC into the following three bins:

- AT < 8 ^oC
- 8 ≤ AT < 18 ^oC
- 18≤ AT < 27 ^oC

Accordingly, we count the number of days within each interval for each municipality and year-month.

2.2.3 Temperature range

In order to control for the intraday temperature variation, we define the temperature range as follows:

$$TR[^oC] = HT - LT$$

where HT [^oC] is the air highest daily temperature and LT is the air lowest daily temperature.

The bins for counting the fraction of month referring to each of them are the same applied for AT. This control variable is added to our empirical specification only as a robustness check of our baseline estimation.

2.2.4 Precipitation

Regarding precipitation we define for each municipality two variables: fraction of days in a month without rainfall (i.e. precipation below 2 mm) and with rain (i.e. precipitation above 2 mm). This quantity corresponds to the typical sensitivity of a rain gauge.[11]

2.2.5 Relative humidity

Finally, we control for relative humidity (RH) as higher percentage may have negative effects on human health. RH is defined as the ratio between the vapur pression and its value at the saturation, the maximum value that it can attain at that temperature (t in ^oC):

$$RH = \frac{e(t)}{e_{sat}(t)}$$

[11] We also test the robustness of our findings to different thresholds of rain, (i.e. distinguishing the raining days according to several levels of precipitation observed, but as findings do not change we adopt the definition aforementioned).

where $e_{sat}(t)$ is calculated as follows:

$$e_{sat}(t) = e_{sat}(0)e^{\frac{at}{b+t}}$$

where $e_{sat}(0) = 6.11$ hPa , a=7.5 and b=237.3^oC

Thus, RH takes values between 0 and 1, meaning that as higher is its value as wetter is the weather.

2.2.6 Summary statistics

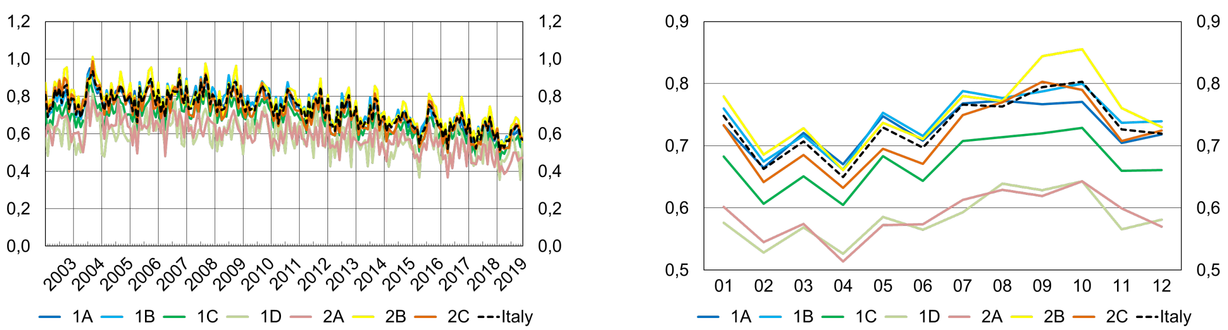
Table 1 summarises the daily births and the key climate variables both at national (i.e. all municipalities) and ecoregions level. In Italy, on average there is 0.73 births per 1,000 population during our sample period. The mean daily AT (in Celsius degrees) between 8-18, 18-27, 27-32 and above 32 is approximately 10.8, 9.1, 4.5 and 1.6 days per month, respectively. On average, the number of days without rainfall per month is about 23, whereas the days with relative humidity very high (above 90%) are 1.5. With reference to ecoregions, we notice that births per 1,000 population is heterogenous across groups. In particular, the highest value, in line with the overall mean, is reported by ecoregion Po Valley, whereas the lowest ones is of ecoregion referred to Illyrian areas. For days with a high mean AT (i.e. between 27-32^oC), we report that the lowest value is observed in the municipalities included in the Alpine areas and the highest is belong to those of the Tyrrhenian area. The average daily AT is above 32^oC approximately 2.6 and 2.7 days per month in the Tyrrhenian and Adriatic areas, compared with only 0.4 days in the Alpine areas. Days per month without precipitation are largest in the coastal areas, namely Italian part of Ligurian-Provencal, Tyrrhenian and Adriatic areas. Finally, regarding relative humidity, the areas with days above the national mean are Alpine, Po Valley and the Italian part of the Illyrian. Figure 5b documents that natality rates are decreasing over the sample period, especially in the last decade, and this negative trend is common across municipalities, although levels are heterogenous between ecoregions. Figure 5, then, shows a clear seasonality in births, with a peak around September-October and heterogeneity among ecoregions.

Table 1: Summary statistics

Sample	All	1A	1B	1C	1D	2A	2B	2C
Births per 1,000 pop	0.73	0.73	0.74	0.67	0.58	0.59	0.75	0.72
Mean AT<8	4.4	8.2	5.4	3.3	5.0	2.5	1.0	1.8
8≤Mean AT<18	10.8	10.3	10.0	11.4	10.7	12.5	11.6	11.6
18≤Mean AT<27	9.1	8.8	8.9	9.2	9.1	9.5	9.8	9.3
27≤Mean AT<32	4.5	2.8	4.7	4.9	4.6	5.0	5.5	5.0
Mean AT>32	1.6	0.4	1.5	1.7	1.1	1.0	2.6	2.7
No Precipitation	23.3	22.2	23.2	23.2	22.3	24.6	24.3	24.4
Precipitation ≥2mm	7.2	8.3	7.2	7.2	8.1	5.8	6.1	6.1
Relative humidity	1.5	2.0	2.0	1.3	1.8	0.8	0.6	0.8
Number of Municipalities-Months				204				
Number of Municipalities				7,565				

Notes: 1A - Alpine, 1B - Po Valley, 1C - Apennine, 1D - Italian part of the Illyrian, 2A - Italian part of Ligurian-Provencal, 2B - Tyrrhenian, 2C - Adriatic.

Figure 5: Natality rates in Italian ecoregions



(a) Monthly births per 1,000 pop. **(b)** Births per 1,000 pop., by calendar month.

Notes: Panel (a): monthly time series of CBR (live-born births per 1,000 population), weighted by population size in each municipality, across Italian ecoregions. Panel (b): average number of live-born births per 1,000 population in each calendar month (01 = Jan; 12 = Dec) over the period 2003-2019, weighted by population size in each municipality; by ecoregion.
Source: our elaboration on Istat data.

3 Empirical strategy

We analyse the effect of climate fluctuations on the birth rates at Italian municipalities level over the period 2003-2019 by using the following panel regression specification:

$$Y_{m,t} = \sum_{j}^{J}\sum_{k}^{K} \beta_k^j \mathbf{AT}^j_{m,t-k} + \sum_{k}^{K} \gamma_k \mathbf{P}_{m,t-k} + \sum_{j}^{J}\sum_{k}^{K} \sigma_k^j \mathbf{RH}^j_{m,t-k} + \alpha_t + \delta_m + e_{m,t} \tag{1}$$

where Y is the log of birth rate in the municipality m at year-month t. AT is a vector of J temperature bins that captures the distribution of daily average apparent temperatures in municipality m in year-month t-k. In particular, to better describe the Italian climatological situation, we apply the interval range described in Section 2.2.2 to define the different risk exposure of individuals. The bins denote the fraction of each month when daily mean apparent temperatures (still in Celsius degrees) are <8, 18-27, 27-32, >32, with 8-18 the reference category. P is a vector of precipitation controls. In particular, we control for the fraction of days in the year-month t-k with rainfall with more than 2 mm. The omitted category is the fraction of the year-month with no precipitation. RH, (see Section 2.2.5) is a vector of relative humidity controls. It is worth to notice that RH is important climate parameter since it indicates if water vapor may condensate. We define this explanatory variable as the fraction of days in the year-month with the relative humidity higher than 0.9 (see Section 2.2.2). α_t represents the year-by-calendar-month fixed effects, which control for time-varying factors that are common to all municipalities, such as national business cycles. δ_m denotes the municipality fixed effects, which captures the unobserved time-invariant municipality effect. $e_{m,t}$ is the error term. Standard errors are then clustered at municipality level to allow for unrestricted serial correlation in the errors within municipalities over time. To capture a potential dynamic relationship between birth rates and climate we then allow birth rates in year-month t to be affected by climate conditions across exposure months 7-12. As a robustness check, we also control of daily temperature variation, which helps account that results are not affected by potential intraday temperature extremes. Finally, since the weather conditions are strongly related to some specific geographic characteristics such as latitude, elevation, proximity to the sea, etc., we also provide estimates by splitting the sample according to Istat ecoregions classification (Section 2.1) as well as to the degree of urbanization and to the altitude level. The objective is to investigate whether findings are more severe in municipalities sharing more homogenous characteristics than others.

4 Results

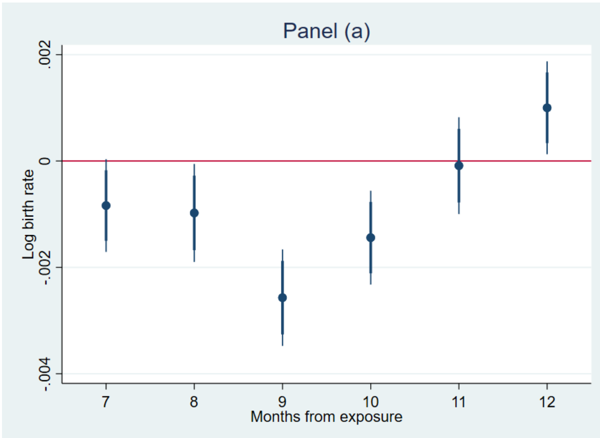
4.1 Main results

We explore the relationship between climate conditions and natality rates across municipalities and over the period 2003-2019 by applying the model specification introduced in Eq. 1. In particular, we provide evidence by linking birth rates in month t with daily climate indicators in the interval period at t-7 up to t-12. Since we do not have the exact date of conception, in this manner we can cover the entire exposure period as well as a couple of months before (i.e. 11 and 12 months before birth), which can help to document potential rebound in births. Although we control for several climate indicators, our discussion is focused only on the ones that are more effective in influencing birth rates, namely temperature bins.[12] Figure 4.1, panel (a), plots the effects of one day above 32^{o}C relative to one day in the 8-18^{o}C temperature bin on the log birth rate across the full set of exposure months selected. The estimates report that each additional day above 32^{o}C causes birth rates to fall by approximately 0.26% nine months later, 0.14% ten months later, and both these effects are statistically significant. The largest effect registered at *t-9* is consistent with *hot days* having a relatively immediate impact on conception probabilities. Considering that the average number of monthly births over our sample period is 42,437, a reduction of 0.26% for each day above 32^{o}C implies about 110 fewer births in Italy per each day above this threshold. If we added up the negative effect associated to the month *t-10* as well as *t-9*, we have an average daily reduction in births at national level of about 170.[13] Figure 4.1, panel (a), also documents a sizeable rebound in births at month 12 after the temperature shock, which causes an increase in births of 0.1%. Overall, the rebound in month 12 offsets 25% of the decline in months 9-10 (0.0010/0.0040). The temperature-fertility response function linking birth rates in month *t* with daily temperatures in month *t-9* to explore the effect of temperature across the entire range of its distribution is presented in Figure 4.1, panel (b). We notice that the sign is negative and statistically significant for days with a temperature bin in the following interval ranges: 18-27^{o}C, 27-32^{o}C and above 32^{o}C; whereas the effects are not statistically significant for the bin <8^{o}C. Overall, the critical temperature knots are those that refer to warm and *hot days* (above 18^{o}C) relative to the reference group temperature bin (i.e.8-18^{o}C). In particular, the suggestive evidence of the temperature-fertility relationship reports a large and statistically significant decrease in births rates nine months later, and the magnitude increases as temperature becomes higher. In sum, our estimates document that the temperature-fertility relationship has a tipping point at a daily mean AT of 18-27^{o}C, but to a lesser degree than above 32^{o}C.

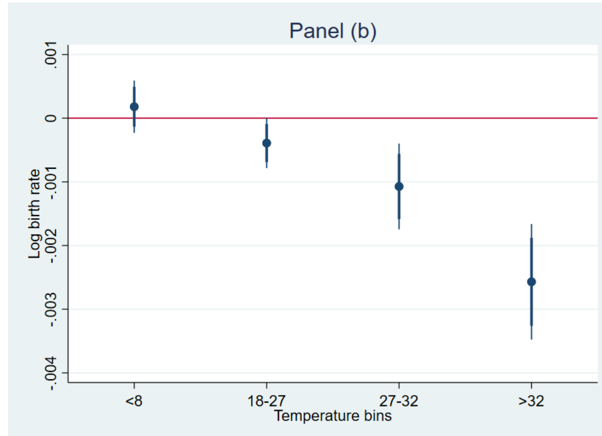
[12]Overall, precipitation and relative humidity do not affect our outcome variables, and this finding is stable over supplementary specifications. Furthermore, our main results are confirmed even when we introduced as controls temperature range variables.

[13]The magnitude of the coefficient at month 10 may refer to both conception within the expected gestational length (i.e. as we cover birth over the all month) as well as births with atypically long gestational lengths).

Figure 6: Estimated temperature-fertility relationship: Effect of daily mean apparent temperature on log birth rate.



(a) Effect of daily mean temperature



(b) Effect of daily mean temperature 9 months later

Notes: The dots are the point estimates, and the shadow line represents the confidence interval. The estimates can be interpreted as the impact on the log monthly birth rate, in log points, of one additional day with a mean temperature >32^oC relative to 8-18^oC. The model has year-month fixed effects, municipalities fixed effects. We control for fraction of days with precipitation in each month. In addition, we control for effects 7-12 months after exposure. Standard errors are clustered at the municipality level.

4.1.1 Robustness check: estimates by ecoregions

Considering that municipalities are extremely heterogenous between them in terms of climate, biogeographical, physiographics and hydrographic factors, such differences may lead to different degree of adaptation in response to average temperatures exposure. As a result, to investigate potential variation in temperature-fertility relationship, we estimate sub-samples of municipalities by using the ecoregions classification provided by Istat. Table 2 reports the coefficients associated to the temperature bin above 32^oC relative to the reference temperature knot (i.e.8-18^oC) over the months 7-12 before births, for each ecoregion. With reference to the ecoregion 1A - Alpine municipalities -, where the individuals are less used to highest temperature (average days above 32^oC are 1.1 vs 3.3 at national level), the sign over the months 7-12 is always negative, but it is statistically significant only at month 8. In this ecoregion, an additional day above 32^oC causes a reduction of 0.4% in births eight month later. In the Po Valley ecoregion, one hottest day at 9-10 months implies a birth reduction of 0.5%, which is partially offset by a rebound at month 12. No effects are instead registered for the ecoregions 1C (Appenine area) and 2C (Italian part of Adriatic).

No effects are instead registered for the ecoregions 1D (Italian part of the Illyrian) and 2A (Italian part of Ligurian-Provencal). Finally, the warmest ecoregions are the most affected by additional days above 32^oC. In particular, for the Tyrrhenian ecoregion (2B), the difference with the whole municipalities at month 9 is meaningful: one >32^oC day causes a 0.3% decrease in births, and the cumulative reduction in births over the period 7-11 is equal to 0.5%, although a rebound at month 12 of 0.2% reduces this total effect. These results suggest that an increase in days with very high mean daily temperature negatively affects birth rates both in the less accustomed municipalities, but especially in those that although historically more exposed to high temperature days, they do not report a decline in the temperature-fertility relationship. Clearly, for the latter further investigations are required to exclude the possibility that other unobserved factors may drive this finding.

Table 2: Effect of daily mean temperature above 32^oC relative to 8-18^oC on log birth rate ($\times$ 100) by ecoregions

	Months after temperature shock					
	7	8	9	10	11	12
A. All municipalities	-0.001**	-0.001**	-0.003***	-0.001***	-0.000	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
B. By ecoregions						
1A (Alpine)	-0.001	-0.004***	-0.001	-0.001	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
1B (Po Valley)	0.001	0.000	-0.002**	-0.003**	0.001	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
1C (Appennine)	-0.001	-0.001	-0.001	-0.001	-0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
1D (Illyrian)	0.016	-0.048	-0.019	0.027	0.069**	-0.026
	(0.020)	(0.035)	(0.027)	(0.052)	(0.030)	(0.043)
2A (Ligurian-Provencal)	0.005	0.000	-0.005	-0.013	0.022**	-0.023**
	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
2B (Tyrrhenian)	-0.001*	-0.001	-0.003**	-0.001	-0.001*	0.002***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
2C (Adriatic)	-0.002	-0.001	-0.003	0.001	0.003	0.002
	(0.002)	(0.002)	(0.003)	(0.001)	(0.003)	(0.002)

4.1.2 Robustness check: estimates by level of urbanization

A further source of heterogeneity across municipalities is related to the degree of urbanization, which can help accounting for different lifestyle, level of wealth, pollution, etc. Using the classification described in 2.1, we split our municipalities in three groups, accordingly. Table 3 shows that the magnitude of the effects in months 7-12 is statistically significant in the densely populated areas compared to less populated or rural ones. One day above 32^oC is responsible of 0.5% at month 9, but the effects in months 7-12 is larger (i.e. 1.5%). Overall, for each day above 32^oC at month 9, we then have in big cities an average reduction of 75 births per day, whereas births decline up to 226 over the months 7-12.[14] In small cities, instead, a day with hot average temperature entails a reduction in births 9 months later of about 0.4% each day, but this decrease is partially recovered (reduction of about 50% of the decrease observed over the period 8-10) by the rebound occurred in months 11-12. Finally, with reference to the rural category of municipalities, the total effects of an additional hot day over the period 7-12 causes a total drop in births of 0.4%. These sub-samples estimates indicate that the most significant decline in temperature-fertility relationship is driven by biggest municipalities, as they report a cut in births considerably higher than the overall ones. This result is not surprising, but it is in agreement with the well-known phenomenon of the urban heat island, i.e. a atmospheric layer above urbinazed areas whose thermal properties of the atmosphere are influenced by the covering of the ground with materials with a high thermal capacity and therefore able to retain the heat due to solar radiation for a long time. Consequently, the effects of climate change are exacerbated in urban areas.

Table 3: Effect of daily mean temperature above 32^oC relative to 8-18^oC on log birth rate ($\times$ 100) by degree of urbanization

	Months after temperature shock					
	7	8	9	10	11	12
A. All municipalities	-0.001**	-0.001**	-0.003***	-0.001***	-0.000	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
B. By level of urbanization						
city	-0.006***	0.001	-0.005***	-0.004**	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
small city, suburbs	-0.000	-0.001*	-0.004***	-0.001**	0.001	0.002**
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.0001)
rural area	-0.001	-0.001*	-0.001**	-0.001*	-0.001*	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

4.1.3 Robustness check: estimates by altitude

The last robustness check refers to the sub-samples defined exploiting the altitude of municipalities and applying the grouping provided by Istat (see 2.1). Neverthless, this additional classification is based on a specific characteristic that should capture the geographi-

[14]The average montlhy births in big cities is of 15,068.

cal location of a municipalities excluding other attributes that have been considered in the previous estimations. With reference to the five categories analysed, Table 4 shows that the effect of one >32^oC day is statistically irrelevant in the municipalities belong to *internal mountains* and *coastal mountains*, whereas in the *inner hill* group the effect on births is positive at month 12. Municipalities included in the category *coastal hill* show a negative effect at month 9, but this reduction is totally offset at month 12. Finally, municipalities placed in valley areas report a temperature shock in births at month 9 of 0.4%, but the births rebound by 0.005 log points over the month 11-12.

Table 4: Effect of daily mean temperature above 32^oC relative to 8-18^oC on log birth rate ($\times$ 100) by altitude

	Months after temperature shock					
	7	8	9	10	11	12
A. All municipalities	-0.001**	-0.001**	-0.003***	-0.001***	-0.000	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
B. By altitude						
Internal mountains	0.001	-0.001	-0.000	-0.000	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Coastal mountains	0.000	-0.001	-0.001	-0.004	0.004	-0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)
Inner hill	0.000	-0.001	-0.001	-0.001	0.001	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Coastal hill	-0.002	0.001	-0.001*	-0.001	-0.000	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Valley	-0.001	0.000	-0.004***	0.000	0.002**	0.003***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)

5 Concluding remarks

This paper studies the relationship between climate conditions and natality rates across Italian municipalities over the period 2003-2019. We estimate a model where birth rates in month *t* are linked to climatic indicators in the interval period at time *t-7* up to *t-12*. Although we control for several climate factors, our discussion is focused on temperature-fertility response as our results document a tipping point at a daily average apparent temperature of 18-27^oC, but to a lesser degree than above 32^oC. We find that the largest effect at *t-9*, which is consistent with *hot days* having a relatively immediate impact on conception probabilities. On average, for each day above 32^oC, we register a decline in births nine months later of about 110 units, this cut is only partially offsets by a rebound at month *t-12*. The robustness of our results to different specifications and sub-samples makes us confident about the reliability of our estimates. The analysises on ecoregions suggest that the reduction in births is particularly larger in the areas historically more exposed to high temperature (i.e. 2B). Heterogenous effects are shown for altitude and degree of urbanization, too. A significant negative effect emerges especially for biggest municipalities where the cumulative impact decline on birth rates (months 7-12) of one additional day with a mean temperature above 32^oC relative to 8-18^oC is of about 1.5%. In brief, our empirical exercise contributes to shed light on the climatic elements which have been claimed to influence childbearing. The evidence for Italy requires a few considerations. Given that the most significant impact on births is related to *hot days*, it is necessary to consider how climate change may further exacerbate the natality trends in the future. According to the climate study of the ESPON EU research programme[15], Italy, especially the South, is one of the areas of Europe most exposed to climate change. As suggested by many authors (see for instance **?**) the increased warming trend and precipitation decline in the Mediterranean region makes it a climate change hotspot, i.e an area where the temperature increase is higher than the average. Thus, since high temperature has been found as a channel of birth cuts in Italy, to avoid the ongoing reduction of birth rates it is necessary that mitigation and adaptation policies are jointly implemented, accounting heterogeneity across municipalities.

[15]see for details https://www.espon.eu/climate