Mapping Low Fertility in Italy: A Spatial–Temporal Cluster Analysis, 2003–2022

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1 Introduction

Fertility in Italy has long attracted the attention of demographers as one of the most notable cases of persistent below-replacement fertility in Europe. After the baby boom of the 1960s, fertility declined sharply, reaching the lowest-low level in the 1990s, followed by a modest and short-lived recovery in the 2000s (Vitali and Billari, 2017; Goldstein et al., 2009; Sobotka, 2004). Over the period 2003–2022, the General Fertility Rate (GFR)—defined as the number of live births per 1,000 women aged 15–49—briefly increased, peaking in 2008 at 39.8, before entering a renewed phase of decline that brought it down to 33.5 in 2022, a decrease of approximately 15.8 percent. These trends reflect profound demographic transformations that have reshaped both the timing and the intensity of childbearing, together with pronounced spatial heterogeneity across the country. Although fertility change in Italy has been extensively studied, most research has relied on macro-level perspectives, typically comparing regions or provinces. Both cross-European studies (Campisi et al., 2020; Klüsener et al., 2013) and those focused on Italy (Vitali and Billari, 2017; Cazzola et al., 2016; Franklin and Plane, 2004; Kertzer et al., 2009) show that variation in fertility within countries can be as large as, or even larger than, variation between countries (Campisi et al., 2020). Italy, in particular, displays marked intra-national diversity in fertility patterns, with persistent divides between Northern and Southern regions (Vitali and Billari, 2017). However, the spatial dimension of fertility has rarely been explored at finer geographical scales. Only a few studies have analysed fertility at the municipality level. Salvati et al. (2020) examined the spatio-temporal evolution of fertility and economic conditions; Benassi and Carella (2023) investigated the relationship between fertility and population density of Italians and foreigners; and Comolli et al. (2025) analysed parity and age-specific fertility rates for 2022, exploring how they vary according to municipalities' socioeconomic characteristics. While informative, these contributions are mainly descriptive or cross-sectional, and do not fully address how low fertility evolves across space and time at the local level. This study fills that gap by exploring spatio-temporal fertility variation in Italy between 2003 and 2022. Using monthly municipal-level data on General Fertility Rates, it identifies clusters of municipalities where fertility is significantly lower than in the rest of the country. The analysis applies a model-based cluster detection approach, based on an updated and adapted version of the DClusterm methodology (Gómez-Rubio et al., 2019), to investigate how low-fertility areas emerge and evolve over time. This type of spatial analysis is widely used in disease and mortality mapping to detect areas at higher risk of illness or death. Just as disease mapping identifies territories with elevated health risks, this approach allows the detection of areas at risk of very low fertility, providing a new lens for understanding demographic vulnerability. Extending these techniques to fertility research offers a powerful way to visualise local disparities and trace the spatial diffusion of fertility decline.

2 Data and methods

2.1 Data

This study relies on highly detailed Italian data at the municipal level, using the administrative boundaries defined by the Italian National Institute of Statistics (Istat) as of January 1st, 2024. At that date, Italy counted 7,899 municipalities. The study period spans from January 2003 to December 2022. Over these two decades, numerous administrative changes occurred, including municipal mergers, splits, and boundary adjustments. To ensure spatial and temporal comparability, we reconstructed the full administrative history and harmonised all data to the 2024 boundaries. The resulting dataset is structured at the municipality-by-month level and includes, for each municipality, the General Fertility Rate (GFR). Monthly birth counts and resident female population data were obtained from Istat. Because population data from Istat are available on an annual basis, we interpolated values between consecutive years to obtain monthly estimates of women aged 15–49. These monthly estimates were used as denominators to compute consistent monthly GFRs for the 2003–2022 period. In addition to fertility measures, the dataset includes a range of contextual indicators reflecting the local demographic and socioeconomic environment. At the provincial level, we incorporated demographic and economic indicators from Istat, such as unemployment rates by age and sex and per capita value added, which captures the average economic output generated by each resident and serves as a proxy for local economic prosperity. At the municipal level, we included urbanisation degree (dense, intermediate, rural), population density, and an accessibility index measuring proximity to service hubs.

2.2 Methods

To identify areas with significantly low fertility, we adopt a model-based spatial clustering approach implemented through the R package DClusterm (Gómez-Rubio et al., 2019). Originally developed for disease and mortality mapping, this method is particularly suited to detect spatial clusters where the observed outcome (here, low fertility) deviates significantly from expected values. The approach models fertility counts using a Poisson regression, accounting for population exposure and covariates. Potential spatial clusters are represented through sets of dummy variables, and each candidate cluster is tested via a likelihood ratio test to assess whether fertility levels within the cluster differ significantly from the rest of the territory. In our context, this approach helps to identify municipalities where fertility is persistently and significantly below national expectations, extending spatial modelling tools traditionally used for health outcomes to the study of demographic vulnerability.

3 First Results

As a first exploratory analysis, we examined the spatial and temporal variability of fertility across Italian municipalities over the 2003–2022 period (Figure 1). Changes in General Fertility

Rates (GFR) were compared to the national average using z-scores, which measure how much each municipality's change in fertility deviates from the national trend in terms of standard deviations. Positive z-scores indicate municipalities where fertility declined less than the national average or even increased, while negative z-scores correspond to areas where fertility declined more than the national trend. Z-scores around zero indicate municipalities following the national average trend. The z-score map reveals a highly fragmented spatial structure, with marked local contrasts rather than clearly defined regional or provincial patterns. Fertility trends tend to vary sharply even between neighboring municipalities, suggesting that local demographic, socio-economic, and environmental factors play a key role in shaping fertility dynamics across the country.

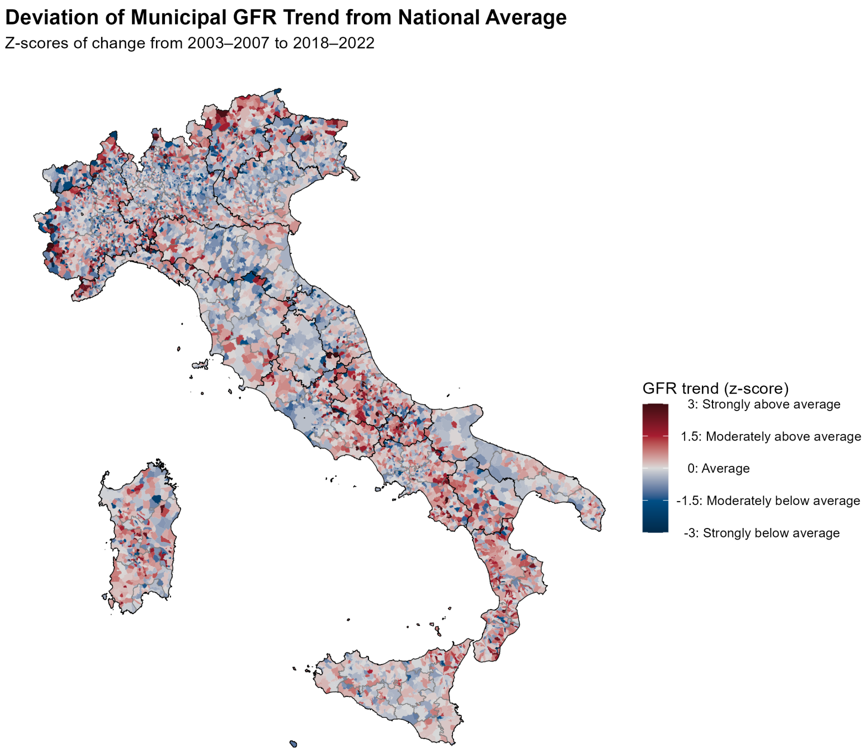

Figure 1: Deviation of municipal GFR trends from the national average. Z-scores of change in General Fertility Rate are shown for the period 2003–2007 to 2018–2022. Values are truncated at ± 3 to emphasize the main variation range.

In a second exploratory step, we identified municipalities with low fertility, defined as those with GFR below the global 10th percentile computed across all municipalities and periods (Figure 2). These municipalities represent the lower tail of the fertility distribution in Italy. To visualize changes over time, we divided the data into four periods (2003–2007, 2008–2012, 2013–2017, 2018–2022) and highlighted, in each period, the municipalities that fell below this global threshold. The maps reveal a clear and growing spatial concentration of low-GFR municipalities. During the early 2000s, these areas were mainly located in mountainous and inland regions, such as the Alpine arc, parts of the northern and central Apennines, and central Sardinia. Over time, low-fertility areas expanded and became more widespread, particularly across the North-Eastern and Central regions, and in some internal and rural parts of Southern Italy. By the most recent period (2018–2022), the spatial extent of low-GFR municipalities had markedly increased, forming broader and more contiguous clusters across large portions of the country. These evolving spatial patterns point to a progressive diffusion of very low fertility beyond the most structurally disadvantaged or peripheral areas.

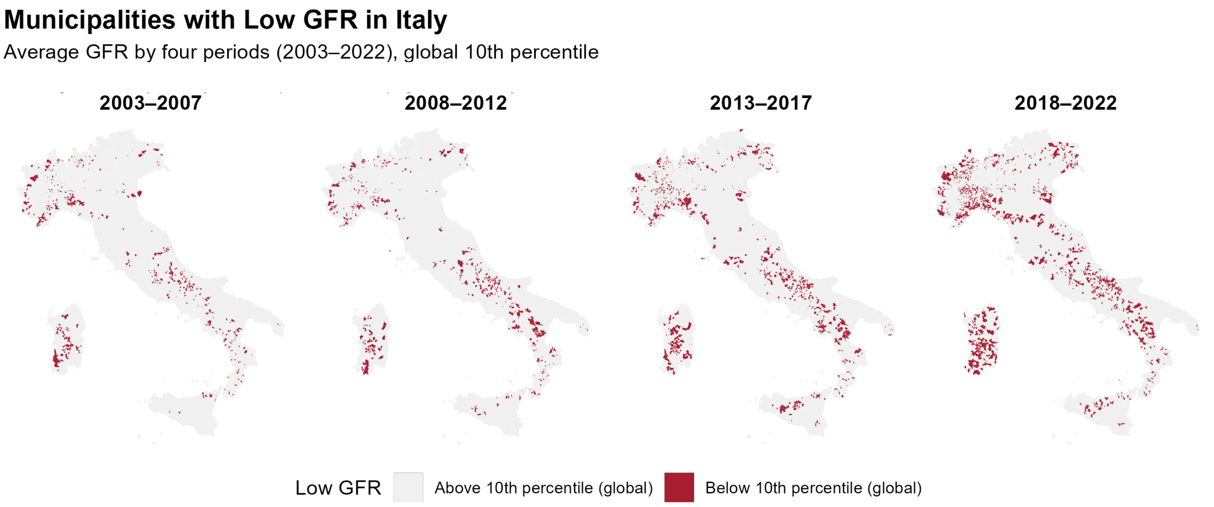

Figure 2: Municipalities with low General Fertility Rates (GFR) in Italy. The maps show municipalities with average GFR below the global 10th percentile over four periods from 2003 to 2022. Areas below this threshold are highlighted, illustrating persistent clusters of low fertility and their evolution over time.

These preliminary analyses provide an initial overview of spatial disparities in fertility and serve as a foundation for the subsequent application of model-based cluster detection, which formally identifies statistically significant low-fertility clusters while accounting for population exposure and covariates.

4 Next steps

The exploratory analyses highlight a highly fragmented spatial distribution of fertility at the municipal level, with considerable heterogeneity across space and time. This pattern motivates the use of a model-based approach at the municipal level, which can formally identify statistically significant clusters of low fertility while accounting for population exposure and local contextual factors. The next steps involve implementing a model-based cluster detection approach using an updated and adapted version of the DClusterm methodology. In this context, the method will be extended to accommodate specific features of fertility data, including the high prevalence of zero GFR values at the monthly municipal level and the seasonal variation in births. By detecting both individual municipalities and clusters of neighbouring areas with an excess risk of low fertility, this approach will provide a fine-grained picture of the geography of fertility decline in Italy.

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