



# Sprawl or Segregation? Local Fertility as a Proxy of Socio-spatial Disparities Under Sequential Economic Downturns

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## Abstract

Although long-term demographic trends have been extensively analyzed in advanced economies, impact of economic downturns on local fertility has been poorly investigated in low fertility contexts. Earlier studies have documented suburban fertility as significantly higher than urban and rural fertility, thanks to a mix of macro (contextual) and micro (behavioral) factors shaping birth rates. In light of the ‘suburban fertility hypothesis’, the present study provides a refined analysis of local fertility rates between 1999 and 2019 at urban, suburban, and rural locations in Athens (Greece), a metropolitan region experiencing sequential expansion and stagnation waves. A superior fertility at suburban locations has been observed during the 2000s and the 2010s, with crude birth rates increasing in socially dynamic and wealthier neighborhoods. With economic expansion, these contexts corresponded with (rapidly growing) industrial districts West of Athens. With recession, these contexts were mostly associated with residential (and service-specialized) neighborhoods East of Athens, with local communities displaying a more effective response to crisis.

**Keywords** Recession · Crude birth rates · Suburban fertility hypothesis · Contextual indicators · Southern Europe

## 1 Introduction

Demographic change is associated with important socioeconomic divides along urban–rural gradients in vastly differentiated contexts around the world (Balbo et al., 2013; Barbieri et al., 2015; Butler, 2004). Economic cycles, migrations, social transformation, and the enhanced volatility in land and housing prices, were responsible together for heterogeneous

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birth rates over metropolitan areas (e.g. Adsera, 2004; Billari & Kohler, 2004; Lerch, 2013). The specific role of such forces has been explored at different spatial scales, evidencing the importance of (i) socioeconomic processes that influence population structures, and (ii) demographic dynamics with distinctive impacts on fertility under specific territorial contexts (Kreyenfeld et al., 2012; Kulu & Vikat, 2007; Liu, 2005; Michielin, 2004; Morgan, 2003). In Europe, changes in local job markets and spatially varying conditions of economic development were associated with fertility before and during the Great Recession (Lesthaeghe & Lopez-Gay, 2013; Sobotka et al., 2011; Van Bavel, 2012). Fertility decline was primarily observed in countries and regions where job market conditions deteriorated with recession (Cabré, 2003; Caltabiano et al., 2009; Fiori et al., 2014; Tragaki & Bagavos, 2014). Spatial gaps in fertility were more intense between dynamic and marginal districts, with limited access to infrastructure, population aging, and low-quality human capital (Arpino & Patrício Tavares, 2013; Bocquier & Costa, 2015; Burillo et al., 2020; Symeonidou, 2000). As a fundamental target of any strategy of regional development in Europe, mitigating socioeconomic inequalities has demonstrated to exert an intrinsic effect on fertility divides (Bernardi, 2005; Hondroyiannis & Papapetrou, 2001, 2002, 2004).

Earlier studies have investigated the intrinsic relation between economic downturns, metropolitan cycles, and fertility dynamics, with the final objective at identifying ‘demographically balanced’ districts—supposed to be more resistant to external shocks (Goldstein et al., 2009; Schneider, 2015; Seltzer, 2019; Vitali & Billari, 2017; Walford & Kurek, 2016). However, the role of external shocks shaping local fertility dynamics was more occasionally investigated in such contexts (e.g. Lerch, 2019; Sabater & Graham, 2019; Tragaki & Bagavos, 2019). Assuming a variable impact of these shocks across districts, fertility levels are a candidate proxy of resilience to short- and medium-term disturbances (Salvati et al., 2020). Considering socioeconomic diversification of local communities, metropolitan scale is an appropriate domain for a comparative analysis of local fertility trends and economic downturns in Europe (Kohler et al., 2002; Kroll & Kabisch, 2012; Kulu & Boyle, 2009)—a continent where fertility regimes responded to intense socioeconomic transformations (Goldstein et al., 2013). In these regards, analysis of economic downturns contributes to re-frame intermediate (regional) and small-scale (local) demographic processes (Frejka & Sobotka, 2008; Gavalas et al., 2014; Georgiadis, 2011).

Recent studies have documented a higher level of fertility at suburban locations in comparison with both urban and rural areas (Kulu, 2013). These stylized facts (better known as the ‘suburban fertility hypothesis’) have been reported for some European regions as a consequence of suburbanization impulses (e.g. Kulu & Boyle, 2009). This hypothesis still requires empirical confirmation in Southern Europe—possibly exploring the additional role of economic downturns and territorial specificities (e.g. Burillo et al., 2020; Kotzamanis & Kostaki, 2015; Polykretis & Alexakis, 2021; Salvati, 2019). In some cases, Mediterranean contexts are still outlined today as resistant to change and impermeable to social innovation (Arapoglou & Sayas, 2009; Georgiadis, 2011; Karamanis & Hyz, 2020; Puig-Barrachina et al., 2020), with traditional socio-cultural, institutional, and political structures—sometimes linked with religious aspects (Martín García, 2010). The present study assumes a diachronic analysis of local fertility over sequential economic phases (i.e. expansion and recession; e.g. Kotzamanis et al., 2017) as key to demonstrate the validity of a ‘suburban fertility hypothesis’ in less investigated social contexts of Southern Europe. In this line of thinking, we propose a spatially explicit analysis covering a period of drastic changes in contemporary Greece, somehow representative of recent socioeconomic transformations on a Mediterranean scale (Dantis & Rizzi, 2020; Hondroyiannis, 2004, 2010; Salvati, 2016). More specifically, we performed an exploratory analysis of a crude birth rate at municipal scale in the Athens’ metropolitan

region (Greece), comparing three sequential periods of expansion and recession (1999–2005, 2006–2012, 2013–2019). Given the inherent crisis affecting Mediterranean countries since 2009 (Cazzola et al., 2016; Del Bono et al., 2015; Modena et al., 2014; Sabater & Graham, 2019), Athens was considered in this study for the paradigmatic response of local fertility to economic downturns at both settlement, city, and metropolitan level (e.g. Di Feliciano et al., 2018). Tragaki and Bagavos (2019) demonstrated how fertility rates in Greece have declined partly as a response to economic uncertainty, with childbearing decisions—mostly of women under age 30, as well as of non-employed women of all ages—being revised downward since the late 2000s. Fertility dynamics observed in the study area represent stylized facts that can be generalized to a broader geographical scale (Bagavos et al., 2008; Gavalas et al., 2014; Tsimbos, 2008; Verropoulou et al., 2007).

Assuming the central role of the local context in determining the spatial variation of fertility rates and the importance of spatially explicit approaches based on macro-demographic data (Muniz, 2009), our work additionally tests if local fertility rates can be an appropriate indicator of economic polarization and social segregation on a metropolitan scale. If, on the one hand, our work is intended to demonstrate the validity of the 'suburban fertility hypothesis' only in certain territorial conditions, the role of 'high fertility traps' (sensu Šprocha & Bleha, 2018) in differentiating local fertility rates over space was highlighted. This allows for a refined interpretation of the socioeconomic contexts behind geographic variations of fertility in advanced economies (Adsera, 2005; Comolli, 2017; Matysiak et al., 2021; Salvati et al., 2019). The time horizon investigated reflects the economic dynamism of Mediterranean cities, the role of major events (e.g. 2004 Olympics), and the increased social permeability of fringe districts (Kandylis et al., 2012; Maloutas, 2007; Panori et al., 2019; Pili et al., 2017). Reflecting together class/ethnic diversification on a regional scale and horizontal (and vertical) segregation of neighborhoods (Arapoglou & Sayas, 2009; Chorianopoulos et al., 2014; Rontos et al., 2016), local fertility dynamics are assumed to outline the legacy of post-war compact urban forms and the incomplete transition towards a truly dispersed settlement model.

## 2 Methodology

### 2.1 Study Area

The investigated area coincides with the Athens' Metropolitan Region (AMR) that occupies a vast mainland district and Salamina island (more than 3000 km<sup>2</sup>), both administered by the regional authority of Attica, Central Greece (Salvati et al., 2018). The area has a mixed topography alternating steep land in mountainous districts and sparse lowlands around the Greater Athens' area (nearly 400 km<sup>2</sup>). Peri-urban settlements developed mainly in Thriasio (Western Attica) and Messoghia (Eastern Attica), two accessible districts originally devoted to agriculture (Chorianopoulos et al., 2014). Boundaries of the study area were defined according with functional criteria (commuting flows) proposed by European Urban Atlas (GMES Copernicus Land initiative of the European Environment Agency), with the aim at delineating homogeneous metropolitan regions in different socioeconomic contexts of Europe (Ciommi et al., 2019). The AMR was administered by 115 local authorities (in Greek, 'dimoi' and 'koinotites') regarded as the elementary analysis' spatial unit of this study (Di Feliciano et al., 2018).

Population density in the area rose from less than 400 inhabitants/km<sup>2</sup> in 1951 to nearly 1000 inhabitants/km<sup>2</sup> in 2011 (Pili et al., 2017). The metropolitan region gravitates on downtown Athens, a municipality extending 40 km<sup>2</sup> with more than 15,000 inhabitants/km<sup>2</sup> (2011). The surrounding conurbation—coinciding with the ‘Greater Athens’ area’—hosted more than 7,000 inhabitants/km<sup>2</sup> in 2011 (Salvati & Serra, 2016). The remaining part of the study area was constituted of suburban locations (municipalities with density > 1000 inhabitants/km<sup>2</sup>) and rural places (density < 250 inhabitants/km<sup>2</sup>). Following the economic expansion culminated with the 2004 Olympic Games (Maloutas, 2007), Greece experienced an intense crisis since 2007—whose effects accumulated and intensified in the following years (Alexandri, 2015)—ending only in 2015 or even later (Vaiou, 2016), with a slow recovery at the end of 2010s (e.g. Balampanidis et al., 2021). Unemployment and poverty, austerity urbanism, reduced public spending, and the consequent cuts in primary services, were significant outcomes of the subsequent recession (Dalakoglou & Kallianos, 2014; Maloutas, 2014; Souliotis, 2013).

## 2.2 Data and Indicators

To evaluate trends over time in local fertility, we used a crude birth rate calculated as a gross fertility index (i.e. the ratio of the total number of children to the total number of women in fertile age, 15–49 years) over a sufficiently long time interval (1999–2019). This indicator has been adopted in earlier studies assessing regional and local demographic patterns (e.g. Burillo et al., 2020; Muniz, 2009; Salvati et al., 2020). While the elementary analysis’ domains selected in our study correctly depict the metropolitan gradient in Athens (Rontos et al., 2016), use of crude birth rates at a detailed spatial scale should be evaluated carefully, since fertility estimates for small areas could be sensitive to external factors (Muniz, 2009). To reduce the impact of inter-annual temporal variability (Burillo et al., 2020), average birth rates at municipal level were calculated over three time intervals of equal length (7 years, i.e. 1999–2005, 2006–2012, 2013–2019) reflecting different steps of the economic cycle in Athens (Olympics-driven economic expansion, stabilization after intense growth/early recession, late recession/early recovery stage). Official statistics of births and population age structure at a given time period and location (municipality) were released from Hellenic Statistical Authority (ELSTAT). We derived the annual number of births (municipal scale) from vital statistics (Salvati et al., 2020). Information on population structure by sex and age at the same spatial scale were taken from the national Census of Population and Households held every 10 years in Greece (1991, 2001, 2011). The background context characterizing each municipality of the study area was profiled using 102 variables selected on the base of the operational indications provided in earlier studies (Di Felicianantonio et al., 2018; Pili et al., 2017; Salvati et al., 2018) and calculated from official statistics and other reliable (public) data sources at both national and international level (SM. Table 1). These variables refer to five analysis’ dimensions appropriately representing the socioeconomic profile of each municipality: (i) territory/topography/accessibility, (ii) settlement characteristics, (iii) land-use, (iv) economic base, income and wealth, and (v) socio-demographic aspects (Salvati & Serra, 2016).

## 2.3 Data Analysis

This study proposed a multi-step approach identifying significant relationships between local fertility and socioeconomic dimensions of urban growth in Athens. These objectives

**Table 1** Indicators describing the statistical distribution of a crude birth rate (children per woman in the age 15–49 years) across municipalities of the study area by time interval

Indicator	1999–2005	2006–2012	2013–2019
Mean	1.41	1.97	1.56
Median	1.37	1.88	1.52
Median-to-mean ratio	0.97	0.95	0.97
Coefficient of variation (%)	22.5	23.2	25.2
Normalized range	1.20	1.24	1.42
Percentile range	0.25	0.29	0.27
Kurtosis	1.77	0.81	1.20
Asymmetry	0.98	0.74	0.49

were addressed using an exploratory approach that integrates (i) descriptive statistics and mapping with spatially explicit analysis (global and local Moran's spatial autocorrelation indexes), (ii) parametric and non-parametric correlations, (iii) a principal component analysis (summarizing the multivariate relationship among contextual variables into few— independent—dimensions characteristic of the socioeconomic profile of each municipality), and (iv) spatial regressions defining the intrinsic linkage between local fertility rates and the selected socioeconomic dimensions mentioned above.

## 2.4 Descriptive Analysis of Local Fertility

Descriptive indicators (mean, median, median-to-mean rate, coefficient of variation, normalized range, percentile variability, kurtosis, asymmetry) were calculated on the statistical distribution of (municipal) crude birth rates by time interval. These indicators delineate the evolution over time of spatial disparities in fertility levels across the Athens' metropolitan region. Chloropleth maps have been realized to illustrate the spatial distribution of crude birth rates by time interval, with the objective of identifying similarities and differences in fertility dynamics at the municipal scale (Burillo et al., 2020). Statistical elaborations were run with PAST 4.10 open software.

## 2.5 Spatially Explicit Analysis of Local Fertility

A global Moran's index of spatial autocorrelation ( $z$ -score) was calculated for periodical birth rates at 5 bandwidths (5, 10, 20, 30, 40 km), testing for spatial dependence at  $p < 0.001$ . Changes over time in Moran's coefficients at different bandwidths estimate intensity and extent of spatial interactions between the elementary analysis' domains over the whole study area. Significant  $z$ -scores indicate a spatial pattern toward clustering at a given bandwidth (Salvati et al., 2019); non-significant scores indicate spatial heterogeneity in local birth rates (Salvati et al., 2020). A diachronic analysis of high-fertility and low-fertility clusters was run calculating local Moran's coefficients of spatial autocorrelation ( $z$ -scores) for each municipality of the study area (Salvati & Serra, 2016). Scores were calculated separately for each time interval and illustrated with chloropleth maps (Ciommi et al., 2019). Based on the local Moran's coefficient, municipalities were classified as (i) high-fertility hotspots (labelled as 'HH') or low-fertility cold-spots ('LL') when  $z$ -score  $> 2$  or (ii) locations with heterogeneous local fertility regimes delineating a steep gradient of high-to-low fertility ('HL') or low-to-high fertility

(‘LH’) when  $z$ -score  $< -2$ . Statistical elaborations and spatial analysis were run with ArcGIS 10 (ESRI, Redwoods, California) software.

## 2.6 Testing the Role of Metropolitan Gradients in Local Fertility

The relationship between local fertility and the distance from downtown Athens was investigated using a U-shaped, polynomial model that assumes higher fertility at intermediate distances from the inner city (suburban locations) and lower fertility at both lower (urban locations) and higher (rural locations) distances from the inner city. To verify the ‘suburban fertility hypothesis’, the Athens’ metropolitan region was assumed as a mono-centric region (*sensu* Salvati, 2014), reflecting a gradient of socioeconomic functions from the inner core to rural countryside based on the linear distance from the central city; suburbs positioned at the fringe of the Greater Athens’ area (Salvati et al., 2020). For each time point, model’s goodness-of-fit was estimated considering the adjusted  $R^2$  coefficient. A Fisher-Snedecor  $F$  statistic was used to test for coefficient’s significance at  $p < 0.01$  against the null hypothesis of a non-significant model (Salvati et al., 2018). To delineate specific territorial contexts associated with high, intermediate and low fertility in Athens, a pair-wise correlation analysis (based on Spearman non-parametric rank coefficients) was run between period fertility rate and individual background variables (Burillo et al., 2020). Significance was tested at  $p < 0.05$  after Bonferroni’s correction for multiple comparisons (Salvati, 2014). Statistical elaborations were run with PAST 4.10 open software.

## 2.7 Identifying Socioeconomic Traits of Urban, Suburban, and Rural Contexts

A Principal Component Analysis was run on a data matrix composed of 102 columns (contextual variables) and 115 rows (municipalities) with the aim at extracting and defining few, independent dimensions that may effectively summarize the socioeconomic profile characteristic of each municipality, following an exploratory multivariate data analysis framework illustrated in earlier studies (Rontos et al., 2016). This approach was grounded on the assumption that background contexts—in both urban and rural areas—are inherently complex in Mediterranean countries (Salvati & Serra, 2016) and a more effective profile of local communities can be better achieved considering a vast ensemble of descriptors than a few individual (although topical) variables—identifying significant socioeconomic dimensions while controlling for redundancy (Di Feliciano et al., 2018). With this perspective in mind, principal components with eigenvalue  $> 2$  were selected and further analyzed for each time interval. In this way, the analysis provided a comprehensive assessment of the socioeconomic forces underlying metropolitan growth and spatial disparities in the study area. Assuming (by construction) the statistical independence among components, loadings (contextual variables) and scores (municipalities) were inspected and illustrated (respectively through tables and maps) to summarize the latent meaning of each extracted socioeconomic dimension (Salvati, 2014). Each component was finally labelled with a representative text string based on a broad investigation of loadings and scores (Di Feliciano & Salvati, 2015). Statistical elaborations were run with PAST 4.10 open software.

## 2.8 Decomposing (Global and Local) Impacts of Socioeconomic Forces on Fertility Regimes

Spatial variability in the relationship between local fertility (the dependent variable) and the background context (taken as a ‘multivariate predictor’) was investigated adopting a mix of spatially explicit regression techniques producing global and local models (e.g. Burillo et al., 2020; Sabater & Graham, 2019; Salvati et al., 2020). In model testing, the choice of the number of predictors is prone to a trade-off between opposite risks, i.e. missing variable bias on the one side, and over-fitting/estimates’ instability, on the other side. We have tackled this challenge condensing the informative content of an impressive set of explanatory variables, likely representative of the background context (sensu Salvati & Serra, 2016), in a limited set of (significant) principal components (see explanations earlier in the methodological section), whose scores were taken as the ‘multivariate predictor’ mentioned above. To mitigate the risk of possible endogeneity caused by inverse causality (Zhou et al., 2019), the original variables alimentering the principal component analysis are lagged from the dependent variable (Gu et al., 2021) for all time intervals.

Cross-section (and panel) spatial regressions producing global estimates were integrated with a local approach based on a semi-parametric Geographically Weighted Regression (GWR) approach. To delineate the most significant variables influencing population dynamics in local systems, a comparative approach based on the use of different regression techniques modelling the joint impact of predictors, allows an indirect assessment of stability in model’s outcomes (Salvati et al., 2019). While presenting a variable goodness-of-fit (i.e. adjusted  $R^2$ ), consistent regression outputs (i.e. the same significant predictors with comparable intensity and sign) may identify a statistically robust (and conceptually relevant) relationship between the dependent variable and significant predictors (Mancini et al., 2018). Changes in the goodness-of-fit of cross-sectional regressions were also regarded as an appropriate indicator of the reliability of the specification over sequential (economic) downturns, indirectly testing the working assumption illustrated above. Comparing the results of different regression models may overcome (or, at least, reduce) the assumptions and limitations typical of each technique used in this study (e.g. Da Silva & Fotheringham, 2016; Elhorst, 2010; Oshan et al., 2019; Yu et al., 2020).

## 2.9 Global Models

To identify significant predictors of the spatial variability in crude birth rates in Athens, global and local models were specified linearly with fertility rate as the dependent variable at location  $s$  (municipality), and with a predictors’ vector that includes the municipal scores of the most significant components selected according to criteria reported in the previous analysis’ step. This relationship was initially tested on standardized input variables separately for each time point using global (spatially implicit) regressions based on Ordinary Least Squares (OLS) and checking the models’ goodness of fit by way of adjusted  $R^2$  coefficients. Inference on regression results (i.e. Student  $t$  statistic on individual coefficients testing against the null hypothesis of zero coefficients with  $p < 0.01$ ) provided an additional criterion for model’s evaluation. To verify violations of the basic assumptions of the general linear model, a Moran spatial autocorrelation coefficient for spatial dependence of residuals was run for each model, testing for significance at  $p < 0.01$  against the null hypothesis of no spatial autocorrelation structure. The (spatially implicit) OLS model



was taken as a baseline for comparison with the refined (spatially explicit) models adopted to cope with the statistical issues mentioned above and presented in the following two sections (Salvati et al., 2018).

Linear regressions were extended using spatial models assuming outcome in one area to be affected by outcomes, covariates or errors in nearby areas, meaning that models may contain (i) spatial lags of the outcome variable, (ii) spatial lag of covariates, and (iii) autoregressive errors. In our case, the lag operator was a  $N \times N$  matrix  $W$  describing the spatial arrangement of the  $N$  units computed by using planar coordinates where each entry  $w_{ij} \in W$  represents the spatial weight associated to units  $i$  and  $j$ . Results' stability was intrinsically verified running three (cross-sectional) models with the same specification and input variables: a Spatial Autoregressive Model (SAR), a spatial autoregressive error term (SEM) and a Spatial Durbin Model (SDM). Both direct and indirect (spillover) effects between municipalities were detected. Best-fit estimation of the proposed models using empirical data was evaluated using pseudo  $R^2$ . Based on the results of cross-section analysis, a spatial panel regression approach was finally run in order to detect the long-term relationship between the dependent variable and the predictors' vector. To verify violations of the basic assumptions of the general linear model, a Geary statistic checking for panel normality, Engle and Hall-Pagan indexes for heteroscedasticity, global Moran and Burridge tests for spatial autocorrelation of errors, and an Anselin test for spatial autocorrelation of spatial lagged dependent variable were run for each model, checking for significance at  $p < 0.01$  against the null hypothesis of no heteroscedasticity and no spatial autocorrelation structure, respectively. Statistical elaborations were run with STATA release 17 (College Station, TX: StataCorp LLC).

## 2.10 Local Models

Results of traditional, spatial econometric models (see above) were enriched with those from semi-parametric GWRs run separately for each time interval, providing a spatially explicit distribution of estimated parameters that include adjusted  $R^2$  and slope coefficients at both global (the study area) and local (municipal) scale. In presence of a large set of predictors (102 socioeconomic variables), the joint use of PCA and GWR contributes to reduce multidimensionality and redundancy of variables profiling local contexts (Salvati et al., 2019). In this vein, GWR incorporates the results of PCA and provides an integral (global–local) overview of the spatial relationship existing between the dependent variable and significant predictors aggregated in few (independent) components. More specifically, we adopted a semi-parametric GWR approach mixing globally fixed and locally varying predictors simultaneously. For each time point, we run separate models with a different composition of globally fixed and locally varying predictors, considering all combinations from a model with all predictors fixed globally to a model with all predictors varying locally. The assumption that principal components were orderly extracted from the most important (i.e. expressing the highest variance in the data matrix) to the less important (i.e. accounting for the lowest variance in the data matrix) and are orthogonal for construction, justifies this analysis' design. Models' performance was tested comparing the (global) adjusted  $R^2$ . Based on these findings, maps illustrating the local-scale impact of each predictor (i.e. principal component) and the local distribution of adjusted  $R^2$  of the selected model were used to summarize the spatial outcomes of regression analysis. Comparison of different models' outcomes provided an indirect assessment of (econometric) specification stability and results' robustness (Mancini et al., 2018). Statistical elaborations were



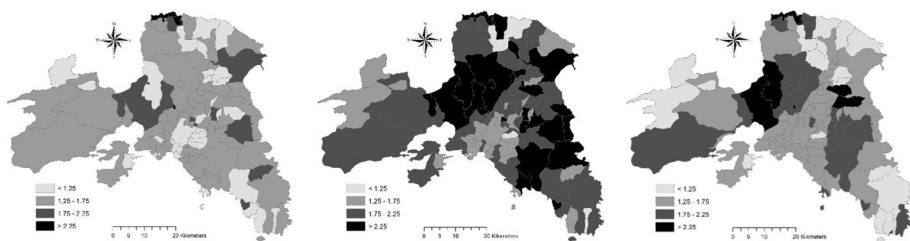
run with the software called ‘Semiparametric Geographically Weighted Regression’ (GWR 4.0.80) Release 1.0.80.

### 3 Results

#### 3.1 Descriptive Analysis of Local Fertility

Fertility levels in the study area increased, on average, from 1.4 children per woman in 1999–2005 to 2.0 children per woman in 2006–2012. A partial decrease was observed in 2013–2019 (Table 1). Median values followed the same trend and the ratio of median-to-mean birth rates resembled 1 over the whole period, indicating a quasi-normal statistical distribution of the investigated variable. Fertility divides along the metropolitan gradient increased moderately with economic expansion and decreased slightly with recession. The coefficient of variation (%) in crude birth rates was relatively low (around 20%–25%), increasing slowly over time. However, the spatial variability of fertility rates among local districts in Athens was relatively high along the study period, as the normalized range of birth rates documents—reaching a peak in 2013–2019. Another indicator of statistical dispersion reflecting spatial heterogeneity—the ratio of the difference between the 75<sup>th</sup> percentile and the 25<sup>th</sup> percentile to the median birth rate (i.e. the 50<sup>th</sup> percentile)—indicated the highest heterogeneity in correspondence with the second time interval. Two morphological indicators of the statistical distribution of the crude birth rates in Athens, kurtosis and asymmetry, delineated more regular forms respectively for the second and the third time intervals. Taken together, these results suggest how, in a low-fertility regime (1999–2005), local birth rates were mostly fragmented and spatially unbalanced. In a high-fertility regime (2006–2012), birth rates were polarized in local hotspots along the metropolitan gradient. The largest variability was observed in correspondence of a mixed fertility regime (2013–2019).

Figure 1 illustrates the spatial distribution of crude birth rates at the spatial scale of municipalities in the Athens’ metropolitan region. Considering three time intervals of equal length, fertility followed a comparable trend over the study period, evidencing a moderate-low fertility in both the Greater Athens’ area and most peripheral, rural municipalities, and a higher fertility in fringe districts surrounding the Athens’ conurbation. As a general pattern, crude birth rates increased between the first and the second time interval and decreased moving from the second to the third time interval (SM. Figure 1). Crude fertility rates in Central Athens ranged between 1.3 and 1.4 births per woman, being quite



**Fig. 1** Crude birth rate (children per woman in the age 15–49 years) by time interval in Athens (left: 1999–2005; middle: 2006–2012; right: 2013–2019)

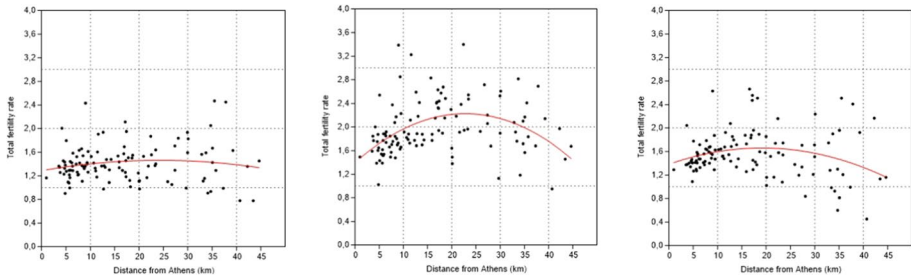
stable over time. Birth rates increased to 1.4–1.5 in the Greater Athens' area, with moderate changes over time. Local fertility rates in the Eastern Athens' suburbs were more heterogeneous, ranging between 1.4 and 1.7 and reaching a local peak in 2006–2012. The highest fertility (between 1.8 and 2 children per woman) was observed in suburban municipalities West of Athens. Fertility was above the substitution rate ( $> 2.25$ ) in nearly 30 suburban municipalities (25% of the total) West and East of Athens only in the intermediate time interval (2006–2012). High-fertility municipalities reduced to 5 units in the following time interval (2013–2019), mostly concentrated in Thriasio and Messoghia districts. Crude birth rates in rural municipalities ranged between 1.2 and 1.4 children per woman, with a slight increase in 2006–2012 and a more marked decrease in the following period.

### 3.2 Spatially Explicit Analysis of Local Fertility

Results of an exploratory analysis of spatial autocorrelation using global and local Moran's coefficients outlined a marked heterogeneity in the geographical distribution of crude birth rates in Athens, with some differences between time intervals. Global Moran's coefficients ( $z$ -scores) were statistically significant for both the first and the second time intervals, indicating spatial clustering at both local (bandwidths  $\leq 10$  km) and regional (bandwidths  $\geq 20$  km) scales, more intense during 2006–2012 (Table 2). Weaker signals of spatial autocorrelation were observed for the third period, with significant coefficients observed at specific bandwidths (10, 20, 40 km). The absolute difference in crude birth rates between time intervals showed a significant spatial autocorrelation structure at all bandwidths. Local Moran's coefficients varied largely in space, revealing dynamic hotspots of fertility that coincide with suburban districts in 2006–2012. The highest polarization in urban (low) and suburban (high) fertility was observed in the same period. A high-fertility hotspot in Western Attica was, however, visible also in the remaining time intervals. A polarization in suburban (high) and rural (low) fertility was more evident during 2013–2019 (Fig. 2). Urban-suburban and suburban-rural polarizations were immediately evident when considering local Moran's coefficients of the absolute difference in crude birth rates between the first and the second (or the second and the third) time intervals (SM. Figure 2).

**Table 2** Global Moran's spatial autocorrelation coefficients of crude birth rate in Athens' metropolitan region by bandwidth and time interval (significant coefficient at \*  $0.001 < p < 0.05$  or \*\*  $p < 0.001$ )

Bandwidth (km)	Crude birth rate (children per woman 15–49 years)			Absolute difference (crude birth rate) over time	
	1999–2005	2006–2012	2013–2019	1999–2005 vs 2006–2012	2013–2019 vs 2006–2012
5	3.48**	3.72**	1.16	3.97**	3.01*
10	4.19**	6.10**	2.64*	5.90**	4.48**
20	3.41**	5.92**	2.02*	5.73**	5.65**
30	3.92**	5.29**	1.53	4.64**	5.08**
40	3.92**	5.71**	2.01*	5.05**	4.70**

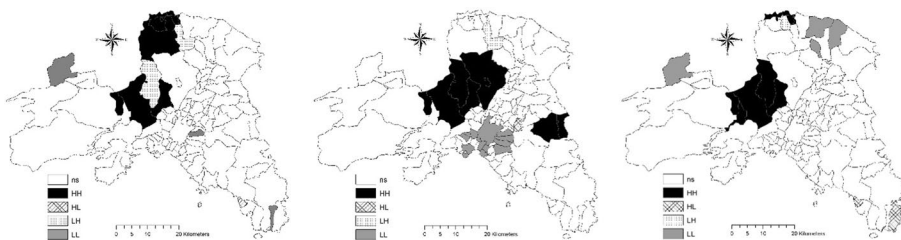


**Fig. 2** Relationship between a crude birth rate (children per woman in the age 15–49 yrs) and distance from downtown Athens (km) by time interval (left: 1999–2005; middle: 2006–2012; right: 2013–2019)

### 3.3 Testing the Role of Metropolitan Gradients in Local Fertility

Empirical results of a polynomial regression confirm a persistently high fertility at suburban locations especially in the second time interval (2006–2012). The coefficient of determination ( $R^2$ ) was low for the first period (0.06), increasing substantially for the second period (0.30), and decreasing slightly for the third period (0.18). Based on the best-fit curve, the highest fertility level was respectively 1.5, 2.2, and 1.6 children per woman in the three sequential time intervals. This peak was estimated respectively at 23, 24, and 20 km far from downtown Athens, corresponding with suburban locations. The polynomial relationship with the linear distance from downtown Athens was more evident when analyzing the absolute difference in fertility rates between time intervals (Fig. 3). A significant, inverse U-shaped relationship was found for the absolute difference in crude birth rates between 1999–2005 and 2006–2012 ( $R^2=0.44$ ). The largest (positive) difference between periods (0.8 children per woman) was estimated at 23 km far from Athens. A significant U-shaped relationship was observed considering differential birth rates between 2006–2012 and 2013–2019 ( $R^2=0.25$ ), and the largest (negative) difference between periods (-0.6 children per woman) was estimated at 25 km far from Athens (SM. Figure 3).

Crude birth rates were correlated pair-wise with background variables delineating a territorial profile for each municipality in the study area, adopting a non-parametric Spearman analysis that quantifies the strength of linear and non-linear relationships between variables (Table 3). Based on a highly selective threshold for significant correlations ( $p < 0.05$  after Bonferroni’s correction for multiple comparison), crude birth rates in the first time interval (1999–2005) were not correlated with any background variable. In the second period



**Fig. 3** Local Moran’s spatial autocorrelation coefficients of crude birth rate in Athens’ metropolitan region by time interval

**Table 3** Non-parametric Spearman pair-wise rank correlation coefficients between contextual socioeconomic variables and crude birth rate in the Athens' metropolitan region by time interval; only significant coefficients at  $p < 0.05$  were reported after Bonferroni's correction for multiple comparisons

Variable	Crude birth rate			Change over time (%)	
	1999–2005	2006–2012	2013–2019	1999–2012	2006–2019
Distance, Athens		0.31		0.29	– 0.39
Distance, Piraeus		0.35		0.27	– 0.45
Distance, Oropos		– 0.29			
Inhab./buildings		– 0.41		– 0.36	0.51
One-dwelling build		0.31		0.33	– 0.33
Residential buildings		0.34		0.33	– 0.38
Per-capita built-up area		0.40		0.33	– 0.50
Compact settlements				– 0.34	0.40
Disc.Med-Dens. Settl		0.33		0.32	
Disc.Low-Dens. Settl		0.36		0.35	– 0.32
Disc.Very-Low d. Sett		0.35		0.30	– 0.37
Isolated structures		0.30		0.26	– 0.41
Fast-transit roads		0.33	0.30	0.27	
Land without curr.use	0.28	0.29	0.36	0.17	
Construction	0.30	0.32			– 0.39
Industry/services					– 0.35
Income growth		0.37		0.32	– 0.38
Commuting rate		0.26			
Aging index	– 0.27	– 0.44	– 0.33	– 0.36	
Working positions	– 0.28				
Building vertical prof		– 0.35		– 0.29	0.43
Building materials		0.28		0.30	
Population age struct	– 0.35	– 0.40	– 0.37		
Soil sealing, 1–5%		0.38		0.44	– 0.30
6–10%		0.39	0.27	0.40	
11–15%		0.40	0.29	0.44	
16–20%		0.38	0.31	0.38	
21–25%		0.31	0.29	0.31	
26–30%		0.29	0.29	0.26	
31–35%			0.27		
36–40%			0.26		
61–65%					0.29
66–70%					0.29
71–75%					0.31
76–80%				– 0.28	0.32
81–85%					0.29
86–90%					0.32
91–95%					0.32
96–99%					0.28
100%					0.30
Job position, ESEC3		– 0.35		– 0.27	0.36

**Table 3** (continued)

Variable	Crude birth rate			Change over time (%)	
	1999–2005	2006–2012	2013–2019	1999–2012	2006–2019
ESEC7		– 0.36		– 0.36	
Low jobs, ESEC9					– 0.26

(2006–2012), fertility levels decreased with population aging and buildings' vertical profile, increasing at the same time with the increase of per-capita income, per-capita built-up area (indicating the dominance of sparse and spatially discontinuous settlements), and the share of soil sealing classes between 6 and 15% in total landscape (reflecting 'sprawled' settlements typical of suburban areas). In the third period (2013–2019), crude birth rates increased with the share of land with no current use in total landscape, more frequent in fringe locations typical of suburban contexts (SM. Figure 4). The absolute difference in crude birth rates between the first and the second time intervals was positively correlated with landscapes having a low percentage of soil sealing (1%–20%). Conversely, the absolute difference in crude birth rates between the second and the third time intervals was correlated negatively with (i) the distance from central cities (Athens, Piraeus), (ii) per-capita built-up area, (iii) per cent share of discontinuous residential settlements in the landscape, (iv) concentration of construction enterprises in total economic activities, and (v) the share of medium-level technical jobs in the local workforce (ESEC4 class). Fertility differentials increased with the per cent share of compact urban fabric in total landscape, buildings' height (a typical traits of consolidated urban settlements), and diversification in the vertical profile of settlements.

### 3.4 Identifying Socioeconomic Traits of Urban, Suburban, and Rural Contexts

Based on the eigenvalue threshold (see methodology), 6 components were extracted explaining a total variance of 57%–58% for all time intervals (all loadings' details provided in SM. Table 2). Significant component loadings (Table 4) were rather stable for the three time points, suggesting a substantial stability of the characteristic socioeconomic structure of Athens over time. Component 1 (22% of total variance) represented a geographical gradient associated with the distance from downtown Athens, confirming the mono-centric spatial organization of the metropolitan region. Urban and rural areas were associated respectively with positive and negative loadings on this axis. Based on these findings, Component 1 was labeled as representative of 'scale and agglomeration' factors. Component 2 (17%) represented affluent (positive) and economically disadvantaged (negative) neighborhoods. Suburban contexts associated with a medium–low percentage of soil sealing, high per-capita income, high percentage of residents with European citizenship, dominance of ESEC 1 and 2 (affluent) working classes in total workforce, received positive loadings. Based on these findings, Component 2 was labeled as representative of an 'income and wealth' gradient. Component 3 (6%) identified a land-use/demographic gradient discriminating industrial sprawl (positive loadings) at fringe locations (with a young population structure and logistic infrastructures as the dominant component of landscape), from consolidated urban areas with residential settlements and elder population. Based on these findings, Component 3 was labeled as representative of 'industrial specialization

and dynamic socio-demographic contexts'. Component 4 (5%) discriminated medium-dense settlements with predominance of native Greek population (positive loadings) from socially mixed and spatially discontinuous, low-density settlements, being representative of 'medium-dense settlements with native population'. Component 5 (4%), labelled as 'economic diversity', outlined an elevation gradient with diversity in businesses, education level, and working position of residents receiving positive loadings, and population aging index receiving negative loadings. Component 6 (4%), labelled as 'advanced services', finally identified a coastal-inland gradient with densities of service/commercial activities and financial enterprises receiving positive loadings.

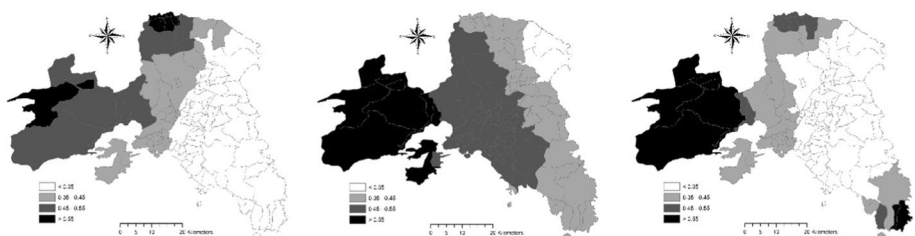
### 3.5 Decomposing (Global and Local) Impacts of Socioeconomic Forces Shaping Fertility Regimes

The six Principal Components (PCs) illustrated above were taken as predictors of local fertility in the study area. More specifically, the selected PCs were assumed to reflect significant (and independent for construction) dimensions of urban growth, summarizing the local background context in a few aggregates that represent the complexity of socio-economic conditions better than individual variables. The empirical findings of the global models are reported in Table 4, distinguishing the results of cross-section (i.e. time-varying) regressions from those derived from panel regressions. Comparing results of the spatially implicit model (OLS) with those of spatially explicit models (SAR, SEM, SDM), a substantial outcomes' stability was observed, both for the goodness-of-fit (adjusted  $R^2$ ) and coefficients' estimates. For all time points, goodness-of-fit progressively increased moving from OLS to SDM. The presence of spatially dependent errors in the OLS model justifies the use of spatially explicit models. The adjusted  $R^2$  trend over time highlights a significant improvement in the goodness-of-fit of all models referring to 2006–2012, a time interval reflecting the late impact of economic expansion on fertility and the social context in Athens. Principal Component (PC) 3 ('industrial specialization and dynamic socio-demographic contexts') was the only significant predictor in all models tested, irrespective of time points and econometric approach. Across models, regression coefficients for PC3 were ranging between 0.14 and 0.19 (1999–2005), between 0.19 and 0.23 (2006–2012) and between 0.10–0.14 (2013–2019). In the SDM, the direct impact of PC3 on the dependent variable resulted to be significant, while the indirect impact remained insignificant, suggesting negligible spillover effects. In addition to PC3, PC4 ('medium-dense settlements with native population') became a significant predictor of local fertility in all models referring to 2006–2012. Regression coefficients for PC4 were stable across different model specifications, ranging between 0.08 and 0.12. Pooling together the observations from the three time points, spatial panel regressions (SAR and SDM) with high goodness-of-fit (adjusted  $R^2$  ranging between 0.62 and 0.64) provided stable long-run results evidencing the unique impact of PC3 on local fertility (coefficients ranging between 0.15 and 0.18). Significant spatial effects (W) in the SAR model and the global Moran index in the SDM justified the adoption of a local regression approach, whose results are illustrated in the following section.

Aggregated results of semi-parametric GWRs modeling different combinations of globally fixed and spatially varying predictors were illustrated in Table 5 reporting together (global) regression coefficients and a global index of goodness-of-fit for each time point. More specifically, according with the operational methodology for extraction of Principal Components, seven models incorporating 6 PCs as predictors were tested for internal

stability and robustness, moving from a model ('6 to 0' in Table 5) keeping all predictors (and model's intercept) as globally fixed to a model performing all predictors (and model's intercept) as spatially varying ('0 to 6' in Table 5). Temporal patterns of both goodness-of-fit and regression coefficients for GWRs were found similar with those recorded for global econometric models (see above). Model's goodness-of-fit systematically increased over time, showing the highest adjusted  $R^2$  for 2006–2012; it also increased substantially when moving from specifications that incorporate only globally fixed predictors to specifications considering only spatially varying predictors. For all time points, however, the adjusted  $R^2$  of the '0 to 6' model (incorporating all predictors (from PC1 to PC6) as spatially varying) was significant for both 1999–2005 (0.37), 2006–2012 (0.43) and 2013–2019 (0.41). PC3 was a significant predictor for all models tested, irrespective of time points and econometric approach. Across models, regression coefficients for PC3 were ranging between 0.17 and 0.20 (1999–2005), between 0.18 and 0.22 (2006–2012) and between 0.07 and 0.13 (2013–2019). In addition to PC3, PC4 was a significant predictor of local fertility in all models referring to 2006–2012 with coefficients ranging between 0.11 and 0.14.

The local distribution of goodness-of-fit indexes and regression coefficients (predictors and model's intercept) was studied for each time point referring to the '0 to 6' model that incorporated all predictors (from PC1 to PC6) as spatially varying and provided the highest (global)  $R^2$ . The outcomes of local regressions were rather differentiated over the three time intervals, indicating a spatially complex impact of the background context on fertility levels in Athens. Local models for 1999–2005 were significant only in the Western side of Attica region. High  $R^2$  coefficients were found in both Western Attica and in the Greater Athens' area between 2006 and 2012. Conversely, high  $R^2$  were observed in Western Attica, and more sparsely, in peripheral, rural locations in Northern and South-Eastern Attica between 2013 and 2019 (Fig. 4). In accordance with the empirical results illustrated above, PC3 was positively associated with crude birth rates for all time intervals, with the highest impact observed for 2006–2012. Local regression coefficients indicate the positive impact of PC3 all over the study area, especially in the first two time intervals (Fig. 5). In the most recent period, the positive impact of PC3 on fertility rates was limited to suburban areas North-West and South-East of Athens. In line with previous findings, impact of PC4 on fertility rates was positive and extended all over the study area for 2006–2012, being less diffused over space for 1999–2005 and 2013–2019. PC1 ('scale and agglomeration') resulted to be negatively associated with crude birth rates for 2006–2012 only in the Greater Athens' area. Negative impacts were limited to some suburban locations in Western Attica during both 1999–2005 and 2013–2019. Conversely, PC2 ('income and



**Fig. 4** Local coefficient of determination ( $R^2$ ) of a semi-parametric Geographically Weighted Regression of crude birth rate in the Athens' metropolitan region (dependent variable) and six principal components (see Table 4) as predictors



**Table 4** Principal Component Analysis of contextual variables at the municipal scale in the Athens' metropolitan region by time interval; only variables with significant loadings >|0.45| were reported (the whole set of loadings was reported in SM Table 2)

Variable	1999–2005						2006–2012						2013–2019							
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6		
Elevation						0.54					0.51	0.49						0.50	0.49	
Distance sea coast																				
Distance, Athens	-0.89						-0.90												-0.90	
Distance, Piraeus	-0.82						-0.81												-0.82	
Distance, Maroussi	-0.73						-0.75												-0.74	
Distance, Aspropyrgos	-0.52						-0.50												-0.51	
Soil Quality Index			-0.48																	
Sparse population	-0.70						-0.61												-0.61	
Inhab./buildings	0.78						0.79												0.79	
Building height	0.82						0.78												0.78	
One-dwelling build	-0.86						-0.69												-0.70	
Residential buildings		0.56											0.61							0.60
Service/commerce buil						0.46														
Multiple usage build	0.68	-0.55					0.52												0.53	
Town master plan	0.49						0.45												0.46	
Per-capita built-up area	-0.49						-0.82												-0.82	
Compact settlements	0.59	-0.54					0.56	-0.56											0.57	-0.54
Disc.High-Dens. Settl	0.65			0.56			0.66			0.57									0.66	
Disc.Med-Dens. Settl		0.76											0.75							0.75
Disc.Low-Dens. Settl		0.69											0.70							0.70
Disc.Very-Low d. Settl		0.45		-0.47									0.47							0.48
Isolated structures	-0.68						-0.68												-0.68	
Other roads	0.84						0.82												0.83	

Table 4 (continued)

Variable	1999–2005						2006–2012						2013–2019					
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6
Land without curr.use			0.50															
Green urban areas	0.46						0.46						0.45					
Cropland	-0.89						-0.89						-0.89					
Manufacture		-0.66						-0.67						-0.67				
Publishing services	0.48						0.48						0.47					
Hotels	-0.62						-0.64						-0.63					
Financial services		0.55						0.55						0.55				
Advanced services	0.51	0.61					0.54	0.57					0.52	0.58				0.45
Commerce		-0.63						-0.64						-0.63				
Industry/services		-0.47						-0.46						-0.47				
Per-capita income		0.85						0.82						0.78				
Income growth								0.49						0.50				
Participation rate	0.53						0.54						0.54					
Commuting rate	-0.60						-0.63						-0.61					
Migration rate		0.47						0.48						0.49				
Aging index									-0.49					-0.46		-0.56		-0.56
Europeans		0.68						0.68						0.69				
Diversity, soil sealing	0.74						0.76						0.75					
Businesses					0.52						0.46						0.46	
Working positions				-0.48						-0.51							-0.51	
Education levels					0.53						0.53						0.54	
Land-use		-0.58																-0.58
Building vertical prof	0.84						0.84						0.84					
Building materials					0.52						0.52							0.52

**Table 4** (continued)

Variable	1999–2005						2006–2012						2013–2019					
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6
Population age struct			-0.56						-0.54						-0.53			
Foreign nationality	0.59	0.45					0.61						0.60					
Income levels	0.57						0.59						0.58					
Soil sealing, 1–5%		0.64						0.66						0.66				
6–10%		0.75						0.76	0.45					0.77	0.46			
11–15%		0.76						0.76	0.51					0.77	0.51			
16–20%		0.76	0.45					0.76	0.51					0.77	0.50			
21–25%		0.79						0.79						0.79				
26–30%		0.76						0.75						0.76				
31–35%		0.68						0.67						0.68				
36–40%	0.51	0.59					0.53	0.57					0.52	0.59				
41–45%	0.56	0.47		0.47			0.58						0.57	0.46				0.55
46–50%	0.64			0.46			0.65						0.64					0.51
51–55%	0.67			0.52			0.68						0.68					0.54
56–60%	0.72			0.49			0.72						0.72					0.47
61–65%	0.78			0.45			0.78						0.78					
66–70%	0.78						0.77						0.77					
71–75%	0.83						0.82						0.83					
76–80%	0.78						0.76						0.77					
81–85%	0.68						0.66	-0.47					0.68	-0.45				
86–90%	0.62	-0.52					0.59	-0.55					0.61	-0.53				
91–95%	0.56	-0.58					0.53	-0.60					0.55	-0.58				
96–99%		-0.54						-0.55						-0.53				
High jobs, ESECI		0.83						0.82						0.83				

**Table 4** (continued)

Variable	1999–2005						2006–2012						2013–2019					
	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6	PC1	PC2	PC3	PC4	PC5	PC6
ESEC2	0.52	0.68					0.55	0.65					0.53	0.66				
ESEC3	0.81						0.81						0.81					
ESEC4	-0.54						-0.53						-0.53					
ESEC6	0.52						0.53						0.53					
ESEC7	0.46	-0.64						-0.66					0.45	-0.65				
ESEC8		-0.76						-0.74						-0.75				
Low jobs, ESEC9		-0.66					-0.45	-0.63						-0.64				
% explained variance	22.3	16.7	5.9	5.3	4.2	3.8	22.2	16.5	5.8	5.3	4.1	3.6	22.1	16.5	5.8	5.3	4.1	3.6

**Table 5** Results of (i) cross-section (global) spatially implicit (Ordinary Least Square, OLS) and spatially explicit (Spatial Autoregressive, SAR; Spatial Error, SEM; Spatial Durbin, SDM) regression Models with crude birth rate as dependent variable (municipal scale, n = 115 observations) and Principal Component (PC, 1 to 6) scores reported in Table 4 as predictors, by year; (ii) a spatially explicit (SAR; SDM) panel regression model (municipal scale, n = 435 observations) with the same specification for the study area

Predictor	OLS	SAR	SEM	SDM	
				Direct effects	Indirect effects
<i>1999–2005 (cross section)</i>					
Intercept	0.0 ± 0.083	0.044 ± 0.084	0.0 ± 0.096	0.330 ± 0.232	– 0.302 ± 0.175
Principal Component 1	– 0.019 ± 0.017	0.001 ± 0.019	– 0.018 ± 0.018	0.053 ± 0.049	– 0.108 ± 0.189
PC2	– 0.006 ± 0.020	– 0.012 ± 0.020	– 0.006 ± 0.020	– 0.012 ± 0.035	– 0.464 ± 0.335
PC3	0.180 ± 0.034*	0.144 ± 0.036*	0.181 ± 0.033*	0.190 ± 0.038*	0.522 ± 0.352
PC4	0.056 ± 0.036	0.031 ± 0.037	0.054 ± 0.035	0.011 ± 0.045	– 0.035 ± 0.490
PC5	– 0.044 ± 0.040	– 0.044 ± 0.040	– 0.044 ± 0.039	– 0.044 ± 0.051	– 0.593 ± 0.448
PC6	– 0.076 ± 0.042	– 0.027 ± 0.046	– 0.075 ± 0.042	– 0.072 ± 0.055	
Adj-R <sup>2</sup> (†)	0.211	0.162	0.253	0.297	
Spatial effects (Moran/Wald) <sup>‡</sup>	3.99*	6.49	0.99	7.23	
<i>2006–2012 (cross section)</i>					
Intercept	0.0 ± 0.073	0.015 ± 0.082	– 0.003 ± 0.033	0.183 ± 0.196	– 0.105 ± 0.151
Principal Component 1	– 0.045 ± 0.015*	0.039 ± 0.022	– 0.047 ± 0.011*	– 0.004 ± 0.041	– 0.326 ± 0.170
PC2	0.034 ± 0.018	0.029 ± 0.022	0.031 ± 0.014*	0.020 ± 0.031	– 0.345 ± 0.268
PC3	0.204 ± 0.030*	0.199 ± 0.033*	0.192 ± 0.026*	0.228 ± 0.034*	0.618 ± 0.321
PC4	0.114 ± 0.032*	0.107 ± 0.037*	0.120 ± 0.027*	0.081 ± 0.040*	1.091 ± 0.420*
PC5	0.076 ± 0.036*	0.068 ± 0.042	0.084 ± 0.031*	0.052 ± 0.047	0.474 ± 0.413
PC6	– 0.072 ± 0.038	– 0.068 ± 0.039	– 0.060 ± 0.033	– 0.122 ± 0.048*	
Adj-R <sup>2</sup> (†)	0.392	0.420	0.422	0.479	
Spatial effects (Moran/Wald) <sup>‡</sup>	12.33*	0.13	0.63	12.14	
<i>2013–2019 (cross section)</i>					
Constant	0.0 ± 0.088	– 0.014 ± 0.090	– 0.003 ± 0.062	0.220 ± 0.243	

Table 5 (continued)

Predictor	OLS	SAR	SEM	SDM	
				Direct effects	Indirect effects
Principal Component 1	0.048 ± 0.019	0.011 ± 0.019	0.005 ± 0.016	0.025 ± 0.051	- 0.084 ± 0.187
PC2	0.026 ± 0.022	0.012 ± 0.023	0.023 ± 0.020	0.069 ± 0.038	- 0.407 ± 0.213
PC3	0.128 ± 0.036*	0.100 ± 0.040*	0.125 ± 0.034*	0.142 ± 0.042*	- 0.349 ± 0.325
PC4	0.065 ± 0.038	0.015 ± 0.048	0.070 ± 0.036	0.030 ± 0.049	0.768 ± 0.397
PC5	0.029 ± 0.043	0.008 ± 0.046	0.025 ± 0.041	0.098 ± 0.058	0.034 ± 0.516
PC6	- 0.062 ± 0.046	- 0.019 ± 0.053	- 0.006 ± 0.043	- 0.062 ± 0.059	- 0.119 ± 0.512
Adj-R <sup>2</sup> (†)	0.102	0.026	0.149	0.208	
Spatial effects (Moran/Wald) <sup>1</sup> 1999–2019 (panel)	0.46	3.34	0.04	8.53	
Intercept		0.019 ± 0.068		0.207 ± 0.187	
Principal Component 1		- 0.009 ± 0.015		0.024 ± 0.039	- 0.161 ± 0.143
PC2		0.010 ± 0.017		0.011 ± 0.029	- 0.142 ± 0.150
PC3		0.151 ± 0.027*		0.184 ± 0.031*	- 0.388 ± 0.239
PC4		0.055 ± 0.028		0.037 ± 0.035	0.406 ± 0.265
PC5		0.004 ± 0.032		0.010 ± 0.043	0.306 ± 0.364
PC6		- 0.050 ± 0.035		- 0.078 ± 0.044	- 0.158 ± 0.348
W (Spatial lag matrix)		0.962 ± 0.438*			
Adj-R <sup>2</sup> (†)		0.636		0.615	
Global (Moran) <sup>2</sup>		0.00		0.03*	
Spatial error (Burrige) <sup>3</sup>		0.35		3.28	
Spatial lag (Anselin) <sup>4</sup>		0.47		2.13	
Homoscedasticity (Engle) <sup>5</sup>		3.82		3.61	
Homoscedasticity (Hall-Pagan) <sup>6</sup>		0.08		0.06	
Normality (Geary) <sup>7</sup>		2.83		3.25	

**Table 5** (continued)

<sup>1</sup>Moran test for spatial dependence (OLS) or Wald test of spatial terms (SAR, SEM, SDM)

<sup>2</sup>(Global) Moran test for spatial autocorrelation of errors

<sup>3</sup>Burridge test for spatial autocorrelation of errors

<sup>4</sup>Anselin test for spatial autocorrelation of spatial lagged dependent variable

<sup>5</sup>Engle ARCH test for panel homoscedasticity

<sup>6</sup>Hall-Pagan test for panel homoscedasticity

<sup>7</sup>Geary test for panel normality; (†) Adjusted R<sup>2</sup> calculated as native R<sup>2</sup> or pseudo R<sup>2</sup>

\*Indicates significance at  $p < 0.01$



wealth') was weakly associated with fertility rates at the local scale for all time points, negatively impacting marginal, rural municipalities in Western and Northern Attica in both 1999–2005 and 2013–2019. A positive impact of PC2 was observed in peripheral municipalities South-East of Athens in both 2006–2012 and 2013–2019. PC5 and PC6 demonstrated to have a less intense impact on fertility rates at the local scale. Impact of PC5 ('economic diversity') in 1999–2005 was negative and limited to marginal contexts of North-Eastern Attica and weakly positive in a few municipalities of Western Attica in both 2006–2012 and 2013–2019. Impact of PC6 ('advanced services') was mostly negative and restricted to more peripheral contexts of Western Attica in 1999–2005, slightly extending its negative effects on North-Western and Northern Attica, respectively in 2006–2012 and 2013–2019 (Table 6).

## 4 Discussion

Understanding spatial fertility variations is crucial for both theoretical and policy-related studies (Boyle, 2003; Evans & Gray, 2018; Fischer et al., 2004). Metropolitan regions in Southern Europe have experienced significant demographic changes, with a shift from a long tradition of rigid family life courses, toward a new regime of delayed marriage, increasing cohabitation, postponement of childbearing, divorce or separation (Bagavos et al., 2018; Gavalas et al., 2014; Rontos, 2010). In such a context, recession led to a profound deterioration of the labor market, with drastic effects on life conditions and demographic behaviors (e.g. Ciganda, 2015; Fernandez-Crehuet et al., 2020; Novelli et al., 2021). Impact of the current economic crisis on Greek fertility was significant (Tragaki & Bagavos, 2019). However, earlier studies on the counter- or pro-cyclical nature of fertility dynamics over economic downturns in Mediterranean Europe have been less conclusive, since empirical results varied largely across regions and over time (Waldorf and Franklin, 2002; Oinonen, 2004; Weeks et al., 2004; Yüceşahin & Özgür, 2008).

Based on these premises, our work demonstrates that suburban fertility was higher than urban and rural fertility in Athens all over the study period, although with some differences during expansion and recession phases. Population aging and high immigration rates seem to have accelerated metropolitan growth and suburbanization with economic expansion (Kandyliş et al., 2012; Maloutas, 2007; Salvati & Serra, 2016), while recession has negatively impacted population dynamics, enlarging social disparities (Di Felicianantonio et al., 2018; Panori et al., 2019; Rontos et al., 2016). These results are in line with earlier evidence collected at a broader scale in Northern Mediterranean countries (Gil-Alonso et al., 2016; Gkartziou, 2013; Sabater & Graham, 2019) and in Western Europe (e.g. Pison, 2011; Sobotka et al., 2011; Wessel et al., 2018).

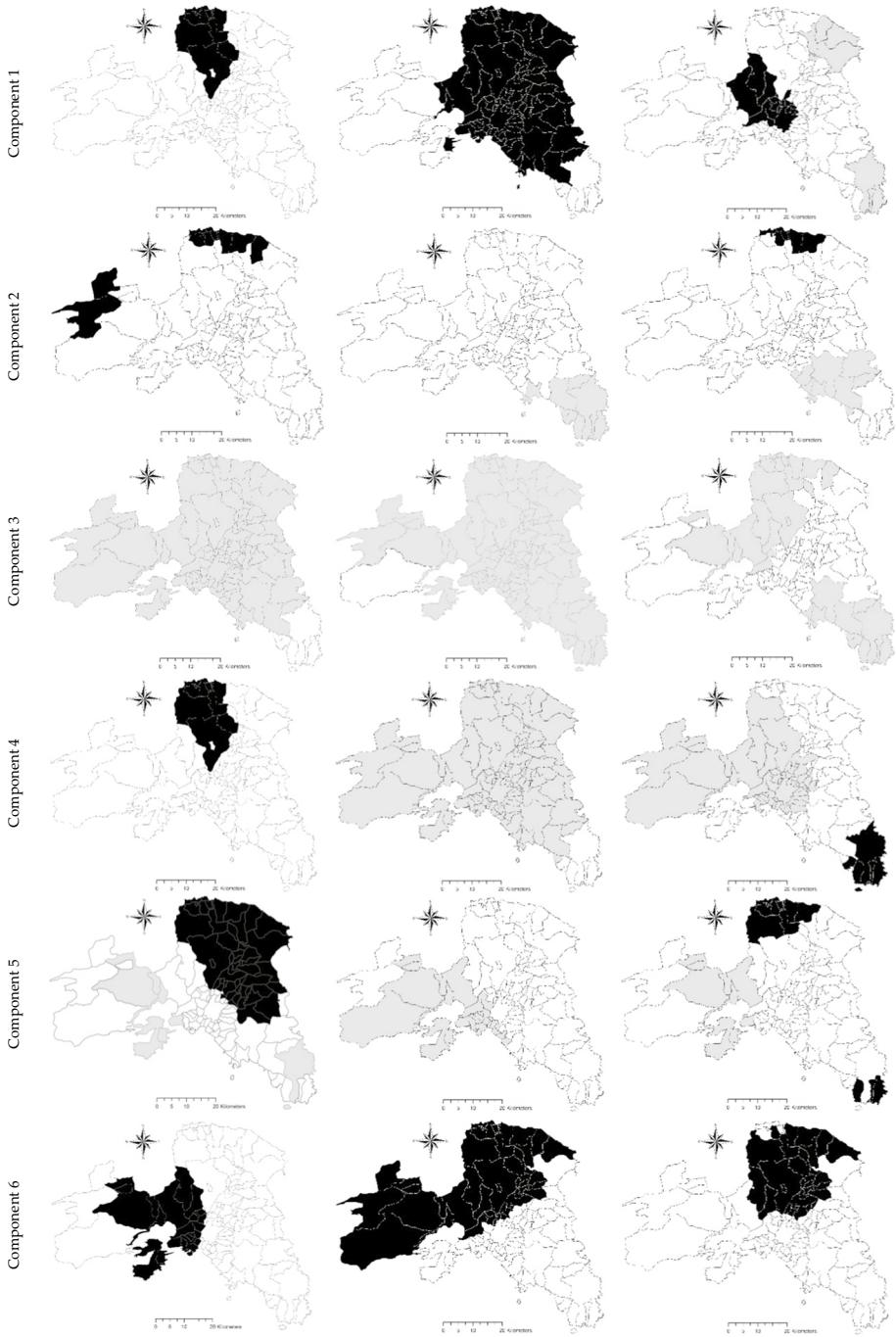
Empirical findings definitely suggest how fertility trends in Athens reflect a mosaic of different sensitivities to expansion and crisis, going beyond the effects of the sole unemployment rate (Rontos, 2010), and responding to a more subtle socio-spatial gradient based on differences in disposable income, class segregation, aging, and concentration of economic activities (Di Felicianantonio & Salvati, 2015), in line with the working assumption of our study. Suburban functions were driving fertility dynamics in both the investigated decades, fueling divides in the birth rates of compact settlements and rural areas (Gavalas et al., 2014). Model's outcomes delineate a relatively modest role of economic agglomeration and scale forces, and outline the importance of (non-economic) contextual factors

**Table 6** Global results of a semi-parametric Geographically Weighted Regression of crude birth rate in the Athens' metropolitan region (dependent variable) and six Principal Components (PCs, see Table 4) as predictors (\* significant coefficient at  $p < 0.01$ ); '6 to 0' up to '0 to 6' indicates the number of fixed (global) to geographically varying (local) variables considered in each model; † indicate a geographically varying (local) variable

Predictor	Model (number of fixed/global to geographically varying/local predictors)	6-0	5-1	4-2	3-3	2-4	1-5	0-6
<i>1999-2005 (cross section)</i>								
Intercept		0.079 ± 0.83	- 6.0 ± 12.64†	- 8.67 ± 22.85†	- 10.46 ± 22.10†	- 5.391 ± 25.58†	1.915 ± 6.48†	1.698 ± 9.62†
PC1		- 0.019 ± 0.017	- 0.004 ± 0.026†	0.006 ± 0.034†	- 0.004 ± 0.037†	- 0.011 ± 0.038†	- 0.019 ± 0.017†	- 0.017 ± 0.020†
PC2		- 0.006 ± 0.020	- 0.007 ± 0.021	- 0.013 ± 0.041†	- 0.014 ± 0.039†	- 0.026 ± 0.048†	- 0.009 ± 0.015†	- 0.009 ± 0.015†
PC3		0.180 ± 0.034*	0.191 ± 0.035*	0.203 ± 0.035*	0.183 ± 0.080†	0.177 ± 0.080†	0.165 ± 0.046†	0.166 ± 0.048†
PC4		0.056 ± 0.036	0.047 ± 0.037	0.026 ± 0.040	0.039 ± 0.038	0.069 ± 0.060†	0.072 ± 0.019†	0.069 ± 0.019†
PC5		- 0.044 ± 0.040	- 0.061 ± 0.043	- 0.074 ± 0.043	- 0.075 ± 0.041	- 0.076 ± 0.042	- 0.048 ± 0.084†	- 0.050 ± 0.085†
PC6		- 0.076 ± 0.042	- 0.083 ± 0.045	- 0.090 ± 0.046	- 0.071 ± 0.044	- 0.068 ± 0.045	- 0.072 ± 0.042	- 0.057 ± 0.050†
Adjusted R <sup>2</sup>		0.204	0.247	0.274	0.356	0.364	0.342	0.365
<i>2006-2012 (cross section)</i>								
Intercept		0.001 ± 7.266	3.059 ± 17.50†	3.702 ± 21.71†	6.530 ± 15.13†	8.170 ± 12.43†	9.945 ± 8.25†	5.413 ± 8.29†
PC1		- 0.045 ± 0.015	- 0.057 ± 0.041†	- 0.053 ± 0.041†	- 0.066 ± 0.028†	- 0.072 ± 0.027†	- 0.075 ± 0.025†	- 0.069 ± 0.019†
PC2		0.034 ± 0.018	0.029 ± 0.019	0.022 ± 0.032†	0.023 ± 0.020†	0.022 ± 0.017†	0.024 ± 0.012†	0.025 ± 0.007†
PC3		0.204 ± 0.030*	0.204 ± 0.032*	0.217 ± 0.032*	0.200 ± 0.035†	0.193 ± 0.034†	0.185 ± 0.029†	0.184 ± 0.025†
PC4		0.114 ± 0.032*	0.131 ± 0.033*	0.124 ± 0.036*	0.127 ± 0.034*	0.136 ± 0.030†	0.137 ± 0.023†	0.136 ± 0.014†
PC5		0.076 ± 0.036	0.037 ± 0.038	0.027 ± 0.038	0.037 ± 0.038	0.041 ± 0.038	0.053 ± 0.049†	0.061 ± 0.035†
PC6		- 0.072 ± 0.038	- 0.090 ± 0.041	- 0.098 ± 0.041	- 0.080 ± 0.041	- 0.078 ± 0.040	- 0.071 ± 0.040	- 0.082 ± 0.047†
Adjusted R <sup>2</sup>		0.387	0.433	0.425	0.429	0.429	0.426	0.434
<i>2013-2019 (cross section)</i>								
Intercept		0.018 ± 8.834	9.315 ± 21.55†	10.283 ± 15.33†	13.014 ± 24.21†	19.531 ± 29.26†	33.252 ± 26.03†	14.347 ± 23.62†
PC1		0.005 ± 0.019	- 0.020 ± 0.053†	- 0.016 ± 0.043†	- 0.032 ± 0.053†	- 0.030 ± 0.079†	- 0.021 ± 0.095†	- 0.030 ± 0.061†
PC2		0.026 ± 0.022	0.036 ± 0.023	0.029 ± 0.043†	0.028 ± 0.050†	0.007 ± 0.065†	0.013 ± 0.067†	0.033 ± 0.036†

Table 6 (continued)

Predictor	Model (number of fixed/global to geographically varying/local predictors)						
	6-0	5-1	4-2	3-3	2-4	1-5	0-6
PC3	0.128 ± 0.036*	0.095 ± 0.038*	0.114 ± 0.039*	0.087 ± 0.113†	0.078 ± 0.112†	0.069 ± 0.102†	0.078 ± 0.081†
PC4	0.065 ± 0.038	0.060 ± 0.040	0.054 ± 0.042	0.059 ± 0.039	0.061 ± 0.109†	0.039 ± 0.115†	0.060 ± 0.069†
PC5	0.029 ± 0.043	0.015 ± 0.047	0.009 ± 0.045	- 0.020 ± 0.043	- 0.025 ± 0.044	0.009 ± 0.137†	0.042 ± 0.098†
PC6	- 0.062 ± 0.046	- 0.038 ± 0.049	- 0.049 ± 0.049	- 0.025 ± 0.049	- 0.021 ± 0.046	0.003 ± 0.046	- 0.078 ± 0.126†
Adjusted R <sup>2</sup>	0.094	0.218	0.212	0.346	0.397	0.394	0.405



**Fig. 5** Local slope coefficients of a semi-parametric Geographically Weighted Regression of crude birth rate in the Athens' metropolitan region (dependent variable) and six principal components (see Table 4) as predictors by time interval (left: 1999–2005; middle: 2006–2012; right: 2013–2019); black and soft grey respectively indicate significant, negative (or positive) coefficients at  $p < 0.05$

at the base of superior fertility of families living in suburban settlements (e.g. Tragaki & Bagavos, 2014).

More specifically, the background context at the base of superior fertility at suburban locations was grounded on a latent socio-demographic dynamism irrespective of the economic cycle (Kulu et al., 2007). However, a particularly high fertility at suburban locations has been observed during the 2000s, in correspondence with a relatively short wave of growth, and was concentrated in residential and wealthy neighborhoods. These findings delineated a latent impact of economic downturns on local communities with a systematically superior fertility levels than neighboring settlements (e.g. Panori et al., 2019). Local regressions also outlined that, with economic expansion, these contexts basically corresponded with (rapidly growing and socially dynamic) industrial districts West of Athens (Rontos et al., 2016). With recession, these contexts were mostly associated with residential (and service-specialized) neighborhoods East of Athens, with local communities displaying a more effective response to crisis (Di Felicianonio et al., 2018). In this direction, these outcomes demonstrates the importance of local contexts to fertility decision-making (e.g. Burillo et al., 2020; Salvati et al., 2020).

Taken together, the empirical evidence of our study is important both from a positive perspective and from a normative point of view. Operationally speaking, the difficulty of defining urban, suburban, and rural areas, complicates empirical verification of the suburban fertility hypothesis using macro-demographic data (Kulu & Vikat, 2007). This explains the fact that such hypothesis has been empirically tested in affluent economies mostly through analysis of individual (life-course) data (Kulu, 2013). Outlining homogeneous areas means, at least indirectly, adhering to a specific model of settlement distribution (e.g. mono-centric, polycentric, scattered) which does not always adapt to multiple and complex metropolitan forms (Salvati & Serra, 2016). In official statistics—and especially in Europe—various systems of territorial nomenclature have been proposed to distinguish urban areas from peri-urban and rural districts (Ciommi et al., 2018). National and regional peculiarities, however, have pushed towards self-referential and hardly comparable classification systems not only between countries but also between regions of the same country with different socioeconomic and territorial characteristics (Serra et al., 2014). Spatial heterogeneity of local fertility rates—in a context of low fertility—has represented one of the distinctive features of the current demographic context, both in advanced countries and in emerging economies (Bayona-Carrasco & Gil-Alonso, 2012; Kabisch & Haase, 2011; Vitali & Billari, 2017). Based on these premises, the use of a basic indicator of fertility from official statistics may assure a comprehensive investigation of past and present fertility trends *vis à vis* social dynamics (Muniz, 2009), accounting for both territorial heterogeneity and socioeconomic change (Burillo et al., 2020). However, production of demographic indicators (with special reference to birth rates) from vital statistics at an adequately refined geographical scale and along sufficiently long time horizons, has been sometimes restricted in European statistical systems (Salvati et al., 2020), limiting the search for contexts with high or low fertility and the socioeconomic factors underlying local variability in demographic processes (Sabater & Graham, 2019).

Together with improvements in official statistics and demographic indicators, our study suggests how the analysis of the impact of social policies supporting fertility levels and enhancing socioeconomic conditions (e.g. reducing poverty, controlling social segregation, and ameliorating housing conditions) should increasingly consider the inherent role of spatial heterogeneity in the local communities forming metropolitan regions (Salvati et al., 2018). Positive (or negative) impact of any possible strategy mentioned above is intrinsically bonded in the spatial complexity of socioeconomic systems at both local (urban) and

metropolitan (regional) scale (Salvati & Serra, 2016). Multi-scale approaches to socio-spatial complexity are an appropriate tool responding to such research and policy challenges in European countries and, broadly speaking, in advanced economies.

## 5 Conclusions

Understanding drivers of spatial differences in fertility rates is a deserving issue in regional science and demography, catching the attention of a number of scholars (see, for instance, Campisi et al., 2020 and references therein). However, scarce, if any, studies tackled the issue at the fine-grain territorial scale adopted in this study, while only a detailed disaggregation of the sample units, associated with techniques explicitly addressing spatial heterogeneity and spatial dependence, could effectively allow for an in-depth analysis of the mechanisms through which spatial proximity and interaction affect fertility behaviors. Taken as a proxy of social disparities in metropolitan regions, a spatially explicit analysis of local fertility rates may additionally inform dedicated strategies toward more cohesive cities. Measures promoting local development and a balanced population structure in metropolitan regions could benefit from a tighter integration with policies containing urban poverty, stimulating class diversification, and orienting spatial transformations toward social cohesion, e.g. mitigating economic polarization and income inequalities. In this line of thinking, the debate on economic crisis and austerity urbanism should be reconnected with a refined analysis of the socio-spatial consequences of demographic processes (and, primarily, fertility dynamics) in metropolitan regions, distinguishing long-term and short-term effects at urban and neighborhood scales. This framework gives room to a more effective interpretation of urban complexity—proposing sustainable, resilient and cohesive solutions to a city growth tuned finely with present (and future) population dynamics.

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