Polycentric Development and Local Fertility in Metropolitan Regions: An Empirical Analysis for Barcelona, Spain

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Abstract

The present study verifies if spatial variability in local fertility reflects the shift from a mono-centric dense settlement model towards a polycentric metropolis organized in central cores and sub-central locations. The spatial distribution of a crude birth rate in Barcelona's province was investigated for a long time span (1975-2018), identifying distinctive trends within five concentric rings around Barcelona at four sub-periods (1975-1985, 1986-1996, 1997-2007, 2008-2018). Using multivariate exploratory statistics, local fertility rates were correlated with background indicators delineating the socioeconomic profile of each municipality in the study area. Fertility rates decreased with the distance from downward Barcelona and with population density. In the first time interval (1975-1985), fertility levels – higher in sub-central municipalities and peri-urban locations than in downtown Barcelona – were positively associated with urban growth. In the following two sub-periods (1986-1996 and 1997-2007), the contribution of local fertility to urban growth decreased significantly, reaching the

lowest-low figures at the end of the 1980s. In the most recent time interval (2008-2018), a moderate (and spatially heterogeneous) recovery of fertility rates was observed in sub-central locations. Demographic processes underlying Barcelona's expansion provide evidence in favor of a positive relationship between polycentric development and local fertility. Our article finally debates on the use of fertility indicators in the assessment of mono-centric *vs* polycentric (metropolitan) growth in advanced economies.
Key words: Urban sprawl; Residential mobility; Multivariate analysis; Demographic indicators; Spain.

Introduction

Polycentric development is a common growth path in contemporary metropolitan regions (Burger and Meijers, 2012; Fernandez Maldonado et al., 2013; Salvati et al., 2019). Recent urbanization has progressively moved away from traditional mono-centric models shifting towards polycentric agglomerations (Parr, 2004; Zhang and Su, 2016; You and Yang, 2017). These transformations have exerted a strong impact on metropolitan structures leading to settlement dispersion and socioeconomic polarization in affluent and disadvantaged neighborhoods (Musterd and van Zelm, 2001; Meijers, 2008; Gilli, 2009). However, while sprawl is frequently associated with negative socioeconomic and environmental consequences, polycentrism combines the advantages of agglomeration economies typical of compact cities and the reduced congestion of decentralized morphologies (Couch et al., 2007; Muñiz and Garcia-Lopez, 2010; Oueslati et al., 2015). In this regard, polycentric development became a 'hegemonic' concept reflecting a more cohesive and spatially balanced growth (Roca Cladera et al., 2009; Vasanen, 2012; Di Feliciantonio and Salvati, 2015).

Identification and characterization of processes and mechanisms underlying polycentric development present inherent difficulties (Garcia-Lopez and Muñiz, 2010, 2011; Veneri, 2013; Pili et al., 2017). Generally speaking, spatial forms, socioeconomic structures and the rapidity of their changes, allow discrimination of mono-centric and polycentric models (De Rosa and Salvati, 2016; Ciommi et al., 2018, 2019). However, earlier studies have distinguished a sort of 'hidden polycentrism' from more subtle and scattered paths of urban expansion (Colantoni et al., 2016; Salvati et al., 2017; Carlucci et al., 2018). A long-term investigation of demographic dynamics in metropolitan regions provides an informative tool to investigate polycentric structures and the related economic functions (Champion, 2001). Analysis of the long-term demographic evolution of residential sub-centers – defined as structural elements of a given metropolitan system (Roca Cladera et al., 2009) – can provide a significant contribution in this direction. At the same time, assessing the spatial evolution of local fertility at different stages of metropolitan development contributes to a refined understanding of urban transitions (e.g. Boyle, 2003; Bocquier and Costa, 2015; Bocquier and Bree, 2018). However, population dynamics underlying polycentric development are still poorly investigated in advanced economies (Champion et al., 2003; Burger et al., 2011; Helbich, 2012). In this context, a spatially explicit analysis of local fertility rates over a sufficiently long time interval allows a better comprehension of complex population trends in polycentric regions.

Considered a reference framework in the analysis of metropolitan regions, polycentrism assumed a normative relevance in the European Union (Vasanen, 2012), being increasingly intended as a pre- requisite for sustainable development (Couch et al., 2007). The Ruhr basin in Germany, the Randstad in the Netherlands, the Po Valley in Northern Italy and the most urbanized areas of Belgium are examples of polycentric regions in Europe (Kabisch and Haase, 2011). These regions are organized into an extensive network of medium-small towns with similar population size and no single urban center, hosting upper economic functions connected with smaller centers embedded in a dense infrastructural network (Parr, 2004).

Contrasting the dominant settlement patterns and trends in Western Europe (Salvati and Carlucci, 2016), compact and mono-centric urban areas are the most frequent metropolitan form in Southern Europe, representing the most affluent regions in the Mediterranean basin (Arapoglou and Sayas, 2009; Carlucci et al., 2017; Cuadrado-Ciuraneta et al., 2017). In this context, demographic transitions have contributed to accelerated urban change, leading to the inherent shift from dense settlements to more scattered and spatially discontinuous morphologies (Gil-Alonso et al., 2016; Salvati et al., 2016; Duvernoy et al., 2018). Contribution of natural growth and migration to metropolitan growth in Southern Europe was particularly heterogeneous over space, being progressively less associated with elevation, accessibility and density gradients (Munafò et al., 2013; Morelli et al., 2014; Salvati and Carlucci, 2017). In such contexts, a complex interplay of socioeconomic forces influenced fertility rates at different spatial scales, from local to regional (e.g. Hank et al., 2001; Kroll and Kabisch, 2012; Lerch, 2013; Gavalas et al., 2014).

By adopting a multivariate analysis of fertility rates made available at enough detailed spatial domains, our study moves in the debate on polycentric development and fertility dynamics in Europe, with a specific focus on the Mediterranean region. Analysis of demographic variables provide a comprehensive view of long-term metropolitan growth (Muniz, 2009; Lerch, 2019; Salvati et al., 2019), integrating more classical indicators of economic agglomeration and scale processes. By combining a comprehensive investigation of the spatial variability in fertility rates with a polycentric vision of urban growth, our work discusses the local outcome of demographic transitions *vis à vis* metropolitan change. We hypothesize that demographic dynamics are spatially asymmetric, being affected by (and in turn influencing) the dominant urban structure (Bayona-Carrasco and Gil-Alonso, 2012). In this regard, we intrinsically verify the contribution of local fertility variations in polycentric development of metropolitan regions, assuming that spatial divides in central places, sub-central locations, and more peripheral areas have an impact on specific demographic behaviors that lead to peculiar fertility trends (Kulu, 2013). More specifically, how local contexts influence fertility levels was investigated in the present study to verify if specific population dynamics have characterized polycentric development in Barcelona, Spain. Barcelona is one of the oldest cities in Spain and has taken centuries to evolve into its present state as a modern metropolis that has benefited from massive infrastructural growth, immigration from Southern Spain, urban regeneration and renewal, and spatially asymmetric peri-urban development over the past decades (Garcia-Ramon and Albet, 2000; Dura-Guimera, 2003; Blanco, 2009). The Barcelona's long-term growth is a paradigmatic example of sequential metropolitan transformations from a mono-centric and compact structure to polycentrism and spatial scattering (Salvati and Carlucci, 2016). The implications of our work for urban management are finally discussed providing policy guidelines for a more cohesive metropolitan growth (Gigliarano and Chelli, 2016).

Methodology

Study area

Extending 7,726 km^2 from the Mediterranean Sea to the Pyrenees (Figure 1), the study area coincides with the administrative borders of the Barcelona's province (the third level of European Nomenclature for Statistical Territorial Units, NUTS), and is partitioned in 311 NUTS-5 municipalities. The area has undulated topography consisting of 30% lowlands, 50% uplands and 20% mountains (Salvati and Carlucci, 2016). Although urban settlements occupy an important part of the area, most of the region is destined to cropland and forests. The study area experienced a massive population increase since the Civil War (Muñiz et al., 2008). While experiencing rapid changes, Barcelona still maintains a wide industrial base specialized in metallurgy, chemistry and pharmaceutics integrated with advanced services and other activities with high value added (Dura-Guimera, 2003). Resident population in Barcelona's province increased from one million inhabitants (1900) to 5.5 million inhabitants (2010), with a different distribution in core city, sub-central locations, peri-urban and rural areas (Cuadrado-Ciuraneta et al., 2017). For instance, at the beginning of the 20^{th} century, more than half of total population resided in downtown Barcelona, decreasing to 30% in

2010 (Bayona-Carrasco and Gil-Alonso, 2012). Peri-urban population expanded more rapidly than inner city and rural population all over the study period. Population growth rates during 1900-1950 were higher in downtown Barcelona than in peri-urban municipalities; the reverse pattern was found in the subsequent period (1950-2010). Population density increased progressively in downtown Barcelona until the early 1980s (from 5.4 thousand inhabitants/km^2 in 1950 to 17.8 thousand inhabitants/km^2 in 1980), decreasing moderately to 16.4 inhabitants/km^2 in 2010. A similar trend was found in sub-central municipalities with a peak density measured in 1980 and a moderate decline afterwards (Salvati and Carlucci, 2016). Although increasing over time, population density in peri-urban municipalities was lower than the average value observed in sub-central locations.

Spatial analysis' unit and territorial structure

Selection of the spatial analysis' unit is a critical issue in urban studies. Administrative boundaries identify the most used spatial domains in regional science. Municipalities have been used largely as the spatial support of basic indicators in regional demography (Couch et al., 2007; Rontos et al., 2016; Salvati, 2016). Municipalities are the smallest spatial domain of most economic and socio-demographic surveys; results of an empirical analysis of data collected at that spatial scale are easily interpretable by non-technical users such as policy-makers and other stakeholders. Finally, although spatial planning is coordinated at the national and regional levels in Spain, municipalities take relevant decisions about land destination, building volume, settlement size, land taxation and other variables influencing population distribution and demographic dynamics (Sabater and Graham, 2019). A spatially explicit analysis of demographic dynamics has further advantages since long-term population data are freely available from official statistics that can be integrated with external data sources and that allow reliable comparisons both across countries and within regions (Salvati and Serra, 2016). For sake of analysis, municipalities in the study area were classified in 5 concentric rings: (i) the central city coinciding with downtown Barcelona, (ii) 32 municipalities surrounding the core city and forming the statutory Barcelona's metropolitan area, (iii) 10 sub-central municipalities, (iv) the municipalities forming the Barcelona's statutory metropolitan region (except for 7 sub-centers), (v) the remaining 147 municipalities of the Barcelona's province outside the boundaries of the statutory metropolitan region (except for 3 sub-centers). This spatial structure was originally proposed by Salvati and Carlucci (2016) as an optimal partition for analysis of polycentric urban growth in Barcelona province (Figure 1).

Identification of sub-central locations

While being originally based on simplified criteria and variables, e.g. urban density, identification of sub-central locations has become increasingly objective and rigorous (Veneri, 2013). Studies carried out in the 1980s and the 1990s proposed the delimitation of sub-centers as a result of the joint application of historical, institutional and administrative criteria (Muñiz and Garcia-Lopez, 2010). Recent studies have used population density, employment density and building types together to identify sub-centers (Roca Cladera et al., 2009; Garcia Lopez and Muñiz, 2010; Fernández-Maldonado et al., 2013). We adopted the classification by Salvati and Carlucci (2016) that used parametric and non-parametric approaches to determine a set of reference thresholds (cut-offs) considering absolute population values at municipal scale.

Seven sub-central municipalities situated within the boundaries of Barcelona's metropolitan region (Granollers, Martorell, Matarò, Terrassa, Sabadell, Vilafranca del Penedès and Vilanova i la Geltrù) were identified according to the criteria mentioned above. They also coincide with sub-central locations identified in Muñiz et al. (2003) and Muñiz and Garcia Lopez (2010) on the base of population, employment and activity density. These are mainly edge cities concentrating jobs in specialized services (business services, as well as finance, insurance and real estate services) surrounded by residential areas. Three additional sub-centers outside the boundaries of the metropolitan region (Manresa, Vic and Berga) were also identified as the head town of the respective rural areas.

Demographic and contextual variables

A crude fertility rate dividing the number of births over a sufficiently long time interval (11 years) by the average number of women in fertile age (15-49 years old) was calculated for each municipality of the study area. The investigated time period was partitioned into four intervals covering 11 years each (1975-1985, 1986-1996, 1997-2007, 2008-2018). We assumed birth rates computed over a sufficiently long time interval as an intrinsically stable measure of local fertility (Muniz, 2009). The total number of births registered in each municipality, and the total number of inhabitants by gender, age and year, were derived from the Spanish Population Register held by the National Institute of Statistics (INE). A total of 20 variables were calculated at the same spatial scale from various official sources (Table 1) with the aim at delineating basic characteristics of the area. Variables include topographic indicators (elevation, proximity to the sea coast), accessibility (road network), agglomeration (population density at the beginning of each time interval), residential mobility (migration balance during each time interval), dummies classifying municipalities in 4 groups based on their location (downtown Barcelona, the metropolitan area, sub-central locations, and the remaining part of the metropolitan region), and linear distances from 11 locations (inner city and 10 sub-centers). Analysis of distances from fixed locations identifies the spatial extent of influence for both inner city and sub-centers (Salvati and Carlucci, 2016).

Data analysis

A data mining approach incorporating descriptive statistics, non-parametric inference, and multivariate exploratory analysis was developed in the present study (Serra et al., 2014). Average local fertility rates were evaluated at five rings for 4 consecutive time intervals (1975-1985, 1986-1996, 1997-2007, 2008-2018). Assuming mean rate and spatial variability as the most representative measures of a regional demographic process (Muniz, 2009), the relationship between average and coefficient of variation in local birth rates was evaluated by year over the entire study period with the aim at identifying regime shifts in local fertility. The spatial distribution of local fertility rates was also illustrated through maps.

Evaluating the spatial structure of fertility rates

By using global and local Moran's indexes computed for the same bandwidth ramp, a diachronic analysis of spatial autocorrelation of local fertility rates was run separately for each time interval with the aim at (i) verifying spatial homogeneity (or diversification) of demographic behaviors over time (global Moran's coefficients) at the regional scale, and (ii) evidencing clusters/spatial outliers (local Moran's coefficients) at the local scale (Salvati and Serra, 2016; Cuadrado-Ciuraneta et al., 2017; Pili et al., 2017). Persistence (or change over time) in spatial regimes of fertility may indicate latent (or substantial) transformations in the regional socioeconomic structure, outlining a more or less rapid transition to new metropolitan structures (Morelli et al., 2014).

A global Moran's index of spatial autocorrelation in total fertility rate was calculated separately for 1975-1985, 1986-1996, 1997-2007 and 2008-2018 considering 6 bandwidths (10, 20, 30, 50, 75, 100) representative of spatial scales spanning from local (10 km) to regional (100 km). This bandwidth's ramp was adopted in earlier studies dealing with socio-demographic processes in Mediterranean countries (Salvati et al., 2019) with the aim at testing the significance of spatial autocorrelation at urban (10, 20 km), metropolitan (30, 50 km), or regional (75, 100 km) scale (Salvati et al., 2016). By analyzing together feature locations and feature values (Zambon et al., 2017), global Moran's coefficients (computed as z-scores) were tested for significance at $p < 0.01$

under the null hypothesis of no spatial relationship in fertility rates. Changes over time in the global Moran's coefficients at different bandwidths provide a comparative estimation of intensity and extent of spatial interactions between the selected analysis' domains (Salvati and Carlucci, 2017).

Assuming that local fertility has reflected, especially in specific time intervals, the urban-rural gap typical of mono-centric regions (e.g. Vitali and Billari, 2017), intensity and statistical significance of spatial dependency in total fertility rate at each municipality and time interval, were respectively assessed over time using local Moran's coefficient of spatial autocorrelation (z-scores) and the related p-levels at 6 bandwidths (see above) reflecting a broad range of spatial interactions, from local (10 km) to regional (100 km). By revealing specific spatial regimes that change (more or less rapidly) over time (Serra et al., 2014), local Moran's coefficients of spatial autocorrelation allow a diachronic investigation of municipal clusters with different fertility trends illustrated through maps. Based on significant ($p < 0.05$) local Moran's coefficients at each location, municipalities were classified in four average spatial regimes as follows: (i) High-High (HH) hotspots (displaying a trend toward high fertility with similar neighbors), (ii) High-Low (HL) clusters (high fertility with different neighbors), (iii) Low-High (LH) clusters (low fertility with different neighbors), and (iv) Low-Low (LL) cold-spots (low fertility with similar neighbors).

The role of local contexts

A non-parametric Spearman correlation analysis was run to assess the pair-wise relationship between birth rates and each territorial indicator described above. Significance of pair-wise correlations was tested at $p < 0.05$ after Bonferroni's correction for multiple comparisons. Results of this analysis allow identification of background indicators with a (linear or non-linear) relationship with local fertility. A Multiway Factor Analysis (MFA) was run on a data matrix with a structure replicated for 4 time intervals that incorporates fertility rates and background indicators (see Table 1) at each municipality in the study area. MFA is a generalization of Principal Component Analysis that allows identification of the multivariate relationship between background indicators and demographic variables and characterization of the most relevant system's changes over time (Salvati and Serra, 2016). By selecting factors with eigenvalue > 1, MFA decomposes the intrinsic dimensions of metropolitan expansion (e.g. agglomeration and scale) into few relevant, independent factors quantifying correlation with local fertility and other demographic variables (population density, migration balance) at the same time.

Results

Fertility dynamics in Barcelona

Total fertility rate in Barcelona province showed a slightly different trend over time compared with what was observed on a country scale in Spain (Figure 2). Fertility in Spain was systematically higher than what was observed in the province of Barcelona until the mid-1990s, when it reached its lowest-low. In Spain, the lowest-low fertility was observed a few years later, in 1998. Subsequently, the fertility rate was systematically higher in Barcelona than in the rest of Spain. A continuous recovery in the fertility rate was observed from the late 1990s to 2008. The fertility rate decreased slowly in the following decade, narrowing the gap between the province of Barcelona and the rest of Spain. Spatial variability in fertility levels was relatively modest in the late 1970s and increased in the 1980s and the 1990s, despite a more intense fertility decline. The highest variability in fertility rate within the study area has been observed since the late 1990s, despite the differential trend in total fertility (increasing between 1997 and 2007, decreasing between 2008 and 2018). Considering fertility rates for homogeneous time intervals, it was observed that downtown Barcelona is the area with the lowest fertility for the whole period considered (Table 2). The rural area outside the Barcelona metropolitan region showed low fertility rates until the mid-1990s, recovering quite rapidly in the subsequent period. The first peripheral crown of Barcelona (metropolitan area) showed high fertility in the first time interval, followed by a rapid fertility reduction in the following period. Sub-central municipalities had the highest fertility rates in the first and fourth time frames. The remaining municipalities in the metropolitan region had high fertility rates, aligned with those recorded in sub-central municipalities in the second and third time intervals, and significantly lower than those recorded in the sub-central municipalities in the first and fourth time intervals. The total fertility rate was significantly different in the 5 areas into which the province of Barcelona was divided for all time intervals considered in this study (Kruskal Wallis H test, $p < 0.05$). Furthermore, the total fertility rate of sub-central municipalities was significantly higher than the total fertility rate of the remaining municipalities in the study area for all time intervals (Mann-Whitney U test, $p < 0.05$). These evidence suggest that fertility rates in Barcelona followed a typical urban-suburban-rural gradient. On average, sub-centers had the highest fertility in the study area.

Figure 3 illustrates the relationship between the average level of fertility at the regional scale and the spatial variability of fertility at the local scale distinguishing among time intervals. Two indicators were analyzed, both of which showed a homogeneous pattern in the first two decades and more heterogeneous patterns in the following years. While constant variability across areas and a slow (but continuous) fertility reduction on a regional scale were observed until the first half of the 1990s, the specific trend observed in the following period suggests a greater unpredictability of regional demographic patterns. These became progressively more heterogeneous over time and space, both in a context of slow fertility recovery (1997-2007) and under a new, and more intense, decline in local fertility (2008-2018).

The spatial distribution of total fertility rate was illustrated in Figure 4. The reduction of average fertility levels between the first and second time intervals was evident, although the spatial distribution of birth rates was rather heterogeneous in both cases. Fertility levels were particularly high in some municipalities, while not directly associated with any geographical gradient. In the third sub-period, local fertility distributed more homogeneously across space. Spatial analysis identified a central belt, which includes the municipality of Barcelona and the neighboring municipalities belonging to the metropolitan area, from a more peripheral belt, which includes rural and mountain municipalities in the Pyrenees region. An intermediate zone with high fertility (corresponding to suburban municipalities) separated these two areas. Sub-central municipalities had the highest level of total fertility. However, a random distribution was observed in the last sub-period, with a clearer distinction between accessible suburban municipalities and marginal areas coinciding with the mountainous region of the Pyrenees.

Spatial analysis of local fertility rates

The analysis of the spatial structure of total fertility rate was carried out using Moran's global and local spatial autocorrelation indices. Table 3 reports the global Moran index separately for the 4 study periods. In the first period, the spatial correlation was significant on a local scale (bandwidths between 10 and 30 km), being not significant on a larger scale (bandwidths greater than 30 km). In the second period, the spatial distribution of the fertility rate proved to be random: a significant Moran's coefficient was only observed for the 20 km bandwidth. In the third period, the Moran's coefficients were significant for all bandwidths, suggesting a highly clustered spatial structure on both urban and metropolitan scale. The same evidence was collected for the last period, with the only exception of the 10 km bandwidth.

Figure 5 illustrates the study area municipalities classified on the basis of the prevailing spatial pattern according to the local Moran's coefficient. Being in line with the results of the global Moran's index, the municipalities classified with a specific and significant spatial pattern (HH, LL, HL or LH) in the first two periods are very few and have a random spatial distribution. In the second period, the local fertility rate showed a more evident spatial heterogeneity in peripheral rural municipalities belonging to the mountainous region of the Pyrenees. A predominance of municipalities with HH (high fertility hotspots on a local scale) in the suburban belt was observed in the third period. Sub-central municipalities and the surrounding municipalities were classified at this spatial pattern. The reverse trend has been observed in the mountainous area, where the municipalities classified as cold-spot (LL) predominate, indicating a homogeneously low fertility rate. The fourth period was finally characterized by a substantial homogeneity of local fertility in the most accessible locations (urban and suburban); a low fertility cold-spot consolidated in peripheral areas.

Analysis of the local context

The impact of local contexts on total fertility rates was tested using Spearman's nonparametric correlation analysis (Table 4). In the first study period, total fertility rate was significantly higher in coastal municipalities and in locations within the metropolitan area of Barcelona. In the second period, fertility levels increased with a positive migration balance and with the distance from Berga. More generally, the highest fertility has been observed in suburban municipalities of the metropolitan region of Barcelona. In the third period, fertility decreased with elevation, the distance from Barcelona and from all sub-centers of the metropolitan region, while increasing with the distance from Berga, population density, migration balance, and accessibility. In the fourth period, fertility levels decreased with elevation and the distance from 5 sub-centers (Martorell, Terrassa, Sabadell, Vilafranca del Penedès, Vilanova i la Geltrù) and increased with population density and migration balance. The local Moran's spatial autocorrelation index of total fertility rate showed no significant correlation with any contextual variable in the first and fourth periods, being significantly higher in Barcelona metropolitan area in the second period. In the third period, the Moran's index increased with elevation and decreased with population density. These results indicate that low fertility rates concentrated in less accessible mountainous municipalities.

The diachronic analysis of the multivariate relationship between demographic variables and contextual indicators (Table 5) extracted three significant axes with eigenvalue > 1 and cumulated variance above 71%. In particular, the first axis explained 36.4% of the total variance, while the second and third axes explained 22.7% and 12.0% of the total variance, respectively. The first axis illustrates the urban concentration gradient in Barcelona. Population density was significantly associated with axis 1 for all study periods, with loadings systematically higher than 0.9 and increasing over time. Migration balance was positively associated with axis 2, displaying intermediate coefficients in the first and fourth periods and very high coefficients in the second and third periods. The total fertility rate was associated negatively with axis 3 in the first and second period, resulting instead positively associated with axis 2 in the third period. Axis 1 was negatively correlated with elevation and the distances from Barcelona and 5 sub-centers and positively correlated with the distance from Berga. Axis 2 was not correlated with any contextual indicator, while axis 3 was weakly correlated with accessibility.

Discussion

As a result of compact urbanization, population growth, economic restructuring and class segregation, metropolitan development in Europe was increasingly oriented towards polycentric models (Vasanen, 2012). In this perspective, the European Spatial Planning Framework has interpreted polycentrism as a target of social cohesion and territorial sustainability (Westerink et al., 2013). Reflecting social homogeneity, dense settlement expansion, and urban congestion, mono-centric models in Southern Europe have revealed peculiar form-function relationships (Carlucci et al., 2017). At the same time, with urban growth being often associated with settlement informality and *lassez-faire* planning (Couch et al., 2007; Munafò et al., 2013; Cuadrado-Ciuraneta et al., 2017), polycentrism in Mediterranean Europe was only partly effective in achieving targets of environmental sustainability, social equity, economic competitiveness and spatial cohesion (Chelli et al., 2016). This is a relevant issue in the case of large cities expanding for a long time in a compact fashion (Di Feliciantonio and Salvati, 2015).

Population de-concentration and suburbanization represents the most recent urban development path in Mediterranean countries (Bayona-Carrasco and Gil-Alonso, 2012). How this path may alter the traditional mono-centric form observed in Mediterranean cities towards a more polycentric spatial asset is an intriguing question (Arapoglou and Sayas, 2009). Use of demographic indicators allows a refined assessment of different morphological and functional dimensions of urban growth in such contexts (Van Nimwegen, 2013; Bradbury et al., 2014; Bocquier and Costa, 2015). Going beyond the lack of long time series of key variables such as employment or building density, our spatially detailed approach benefits from the extensive use of demographic indicators.

These indicators are based on homogeneous time series derived from vital statistics available at a disaggregated spatial scale (Chelli et al., 2009).

The present study definitely contributes to a refined analysis of fertility dynamics in polycentric regions. The lack of a specific analysis of fertility trends in central cities, residential sub-centers, peri-urban and rural areas in Southern Europe, justifies the approach formulated in this study. Assuming that sub-centers are the most relevant engine of polycentric development, our analysis compares fertility rates in core cities, sub-central locations and the surrounding rural areas over a sufficiently long time interval, evidencing the specific role of endogenous and exogenous population growth and the (changing) local contexts in metropolitan expansion. More specifically, this work proposes a model of urban expansion fueled by spatially asymmetric demographic behaviors. Considering four distinct time intervals that reflect divergent demographic patterns at regional and country scale, the analysis carried out on a municipal scale shows a strong differentiation in local fertility. Sub-central municipalities have experienced rapid transformations reflected into differential fertility levels in respect with neighboring areas. With the increasing role of sub-centers, Barcelona expansion was progressively oriented toward polycentrism since the 1980s.

In the last decades, the study area has progressively assumed the typical traits of moderately polycentric regions (widespread and spatially balanced medium-density settlements with a progressive de-concentration of the inner city). Population growth in sub-central municipalities, already observed between the 1950s and the 1980s, continued unaltered in the subsequent decades, slowing down since the early 2010s. Although being sometimes criticized, the Barcelona’s model highlights how inner city de-concentration and endogenous development of sub-central locations has resulted in a more balanced spatial structure. This process was clearly associated with a particularly high fertility of local communities living in sub-central locations during the early 2000s. These findings complement and corroborate the suburban fertility hypothesis, highlighting a specific role for the socioeconomic context typical of sub-central locations.

Kulu and Boyle (2009) observed that fertility levels in Finland were the highest in small towns and rural areas and the lowest in the capital city. While socioeconomic characteristics of women and selective migrations account for a small portion of fertility variation across settlements, housing conditions and contextual effects explain a significant portion of urban–rural fertility variation, especially for the first birth. In Britain, Kulu and Washbrook (2014) demonstrated that (i) fertility levels decline as the size of an urban area increases and that (ii) suburban locations have significantly higher fertility levels than city centers. Fertility differences by residential context persist when controlling for the effect of population composition and selective migrations. By analyzing the cumulative fertility of cohorts whose fertility was completed before and after the change in political regime in 1989, Vobecká and Piguet (2012) argued that education and residential context (urban–suburban–rural gradient) exerted important effects on the cohorts with (almost) completed fertility in the Czech Republic. The rapid increase in the number of babies born in suburban areas between 1991 and 2007 was due to the selective residential migration of young couples and results not just from the larger cohorts of potential mothers but also from the higher fertility of new resident couples owing to their more reproduction- oriented values. While urban-rural dichotomy in fertility levels is a simplification of complex spatial dynamics, these factors are also evident in Barcelona, confirming the specific contribution of sub-central municipalities to higher suburban fertility rates.

Causes of the existence of an intermediate group of municipalities (sub-centers and surrounding locations) with specific fertility trends should be better investigated on a regional scale. Diversification of marriage and childbearing behaviors shaping fertility levels in neighboring locations of the same metropolitan area indicate that urban spillover processes, which have shaped Barcelona's expansion over the last 30 years, are producing sub-central spaces with mixed economic functions and diversified social traits (Dura-Guimera, 2003; Salvati and Carlucci, 2016; Cuadrado-Ciuraneta et al., 2017). Since immigration accounted (and still accounts) for the largest contribution to population growth in sub-central locations (Bayona-Carrasco and Gil-Alonso, 2012), this process has clearly contributed to local fertility, especially in earlier decades.

The empirical results of our study are also coherent with the outcome of earlier studies (e.g. Roca Cladera et al., 2009), indicating the ambivalence of a functionally polycentric model with a morphologically mono-centric form centered on downtown Barcelona. While presenting distinctive fertility traits at the local scale, this ambivalence was reflected sometimes in heterogeneous demographic dynamics at metropolitan scale. These findings suggest that Barcelona's spatial organization can be interpreted as a mixed scattered-polycentric model (Muñiz et al., 2003). While the spatial structure of activities and jobs in the metropolitan region of Barcelona definitely suggests a polycentric location model with distinctive sub-centers (Garcia-Lopez and Muñiz, 2011), morphological indicators indicate only a moderate development around these sub-centers (Salvati and Carlucci, 2016). The spatial distribution of sub-centers (mostly of them distant less than 30 km from downtown Barcelona) may justify these results. Moreover, the less important role of sub-central towns in the rest of Barcelona province (e.g. Berga) indirectly confirms our assumption about the ambivalence of the Barcelona polycentric-scattered model of urban expansion (Zambon et al., 2017).

In these regards, our study indicates how diachronic analyses carried out using local-scale data derived from official statistics are meaningful when debating about the changing spatial organization of metropolitan regions. The empirical results of our study may also inform policies supporting local fertility in spatially balanced regions that can be generalized to other socioeconomic contexts typical of advanced economies. An informative base of indicators assessing formation and consolidation of sub-centers is useful when designing alternative development scenarios for large Mediterranean cities competing with the wealthiest and 'globalized' agglomerations of Western Europe. Results of our study finally demonstrates the importance of interpreting different demographic, economic, and cultural indicators within concrete historical backgrounds (Reher and Iriso-Napal, 1989; Rodriguez-Rodriguez, 2000; Roig and Castro-Martìn, 2007; Rosti and Chelli, 2009). While suggesting that the partial failure of polycentric development reflects the persistence of place-specific social traits and an insufficient participation to planning decisions in Mediterranean Europe, our study indicates the urgent need of strategies promoting a demographic rebalance of central and peripheral areas through specific stimuli for sub-central development and delocalization of high value added activities in peri-urban areas.

From a demographic perspective, polycentric development should support social conditions (e.g. job, housing) leading to equity, cohesion, competitiveness and environmental security (e.g. Chelli and Rosti, 2002; Maloutas, 2007; Rosti and Chelli, 2012). Place-specific and multi-scale strategies stimulating local competitiveness and social targets may identify a new development path oriented toward polycentrism and demographic balance (Lerch, 2016). Our findings contribute to a generalized design of more effective policies that promote regional competitiveness, urban containment and sustainable settlement/housing conditions together, by addressing the specificity of different territorial contexts (e.g. distinguishing sub-central locations from neighboring peri-urban municipalities). Assuming that top-down policies sometimes ignore the complexity of regional dimensions of intervention (Meijers, 2008), place-oriented strategies replacing top-down policies designed at country and supra-national scales seem to be more appropriate to face with this policy target (e.g. Chelli et al., 2016). In this regard, polycentric development is intended as the result of a broader strategy grounded on participative processes raising awareness of local communities to spatially balanced mechanisms of regional growth.

Conclusions

A spatio-temporal analysis of local fertility rates in a representative case of Southern Europe may indicate distinctive development paths from mono-centric to polycentric structures. Fertility rates in sub-central locations were the highest in the study area for a long time, indirectly supporting (and fortifying the theoretical assumptions of) the suburban fertility hypothesis. The novelty of this study lies in the use of simplified and generalizable criteria for identification of demographic dynamics in sub-central locations compared with urban and rural areas. By considering structural fertility changes and spatial variability over a sufficiently long time span, our analysis provides original elements supporting a new interpretation of the long-term expansion of compact cities shifting toward polycentrism. Demographic dynamics underlying Barcelona's growth suggest how the (supposed) heterogeneity in forms and functions of the Mediterranean cities is shaped by place-specific development patterns, the spatial organization of consolidated and new residential settlements and local-scale planning strategies reflecting path-dependent urban morphologies.

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Table 1. List of variables considered in this study.

Variable	Temporal schedule	Unit of measure (range)	Source
Total fertility rate	1975-1985, 1986-1996, 1997-2007, 2008-2018	% (0-100)	IDESCAT
Population density at the beginning of the study interval	1975, 1986, 1997, 2008	Inhabitants/km^2 (0 - ∞)	Resident population by municipality (INE)
Migratory balance (annual rate of growth)	1975-1985, 1986-1996, 1997-2007, 2008-2018	%	
Distance from Barcelona		km (0 - ∞)	Analysis on a municipal map (INE)
Distance from Granollers			
Distance from Martorell			
Distance from Matarò			
Distance from Terrassa			
Distance from Sabadell			
Distance from Vilafrance del Penedés			
Distance from Vilanonova i la Geltrù			
Distance from Manresa			
Distance from Vic			
Distance from Berga			
Proximity to the sea coast		Coastal municipality (1), otherwise (0)	
Road accessibility		Municipality with a motorway (1), otherwise (0)	
Elevation		km (0 - ∞)	
Central city, downtown Barcelona		Dummy	
Metropolitan area			
Sub-centres			
Other municipalities, metropolitan region			

Table 2. Total fertility rate by time interval and district in Barcelona, 1975-2018.

District	1975-1985	1986-1996	1997-2007	2008-2018
Downtown Barcelona*	1.93	1.16	1.29	1.29
Barcelona metropolitan area**	2.21	1.21	1.42	1.46
Sub-centers***	2.25	1.37	1.59	1.59
Barcelona metropolitan region****	2.11	1,39	1.60	1.44
Barcelona province*****	1.97	1.32	1.51	1.55

*the central municipality of Barcelona; ** 32 municipalities belonging to the administrative area of metropolitan Barcelona excluding the central municipality of Barcelona; *** 10 sub-central municipalities in Barcelona province; **** the remaining municipalities of the metropolitan region of Barcelona (excluding the central municipality of Barcelona and 7 sub-central municipalities located in the region); ***** the remaining municipalities of Barcelona province (excluding 3 sub-central municipalities located outside the metropolitan region of Barcelona.

Table 3. Global Moran's spatial autocorrelation index of total fertility rate in Barcelona's province, 1975-2018, by time interval and bandwidth (km); I = Moran's index; *z* = *z*-score of Moran's index; *p* = probability level of Moran's index.

Band	1975-1985			1986-1996			1997-2007			2008-2018		
	I	*z*	*p*	I	*z*	*p*	I	*z*	*p*	I	*z*	*p*
10	0.082	2.68	0.007	0.041	1.38	0.167	0.187	5.97	0.000	0.076	2.50	0.012
20	0.040	2.49	0.000	0.022	2.80	0.005	0.193	11.26	0.000	0.063	3.79	0.000
30	0.032	2.80	0.005	0.023	2.04	0.041	0.178	14.46	0.000	0.055	4.64	0.000
50	0.014	2.12	0.034	0.011	1.77	0.076	0.141	17.49	0.000	0.034	4.49	0.000
75	0.009	2.09	0.037	0.012	2.55	0.011	0.109	18.37	0.000	0.027	5.03	0.000
100	0.008	2.25	0.025	0.008	2.23	0.026	0.089	17.85	0.000	0.023	5.11	0.000

Table 4. Non-parametric Spearman pair-wise correlation coefficients between selected territorial variables and (i) total fertility rate or (ii) local Moran's standardized coefficients of spatial autocorrelation in total fertility rate, Barcelona province, 1975-2018 (only significant coefficients at $p < 0.05$ after Bonferroni's correction for multiple comparisons were shown).

Variable	Total fertility rate				Local Moran's z-score			
	1975-1985	1986-1996	1997-2007	2008-2018	1975-1985	1986-1996	1997-2007	2008-2018
Distance from Barcelona			-0.38					
Granollers			-0.29					
Martorell			-0.38	-0.20				
Matarò			-0.29					
Terrassa			-0.34	-0.18				
Sabadell			-0.35	-0.16				
Vilafranca del Penedès			-0.33	-0.16				
Vilanova i la Geltrù			-0.35	-0.16				
Manresa								
Vic								
Berga		0.17	0.38					
Proximity to the sea coast	0.16							
Accessibility			0.26					
Elevation			-0.33	-0.17			0.18	
Population density			0.20	0.23			-0.26	
Migratory balance		0.42	0.68	0.33				
Barcelona metro. area*	0.16					0.16		
Sub-centres*								
Rest of Barcelona metro.re*		0.17	0.39					

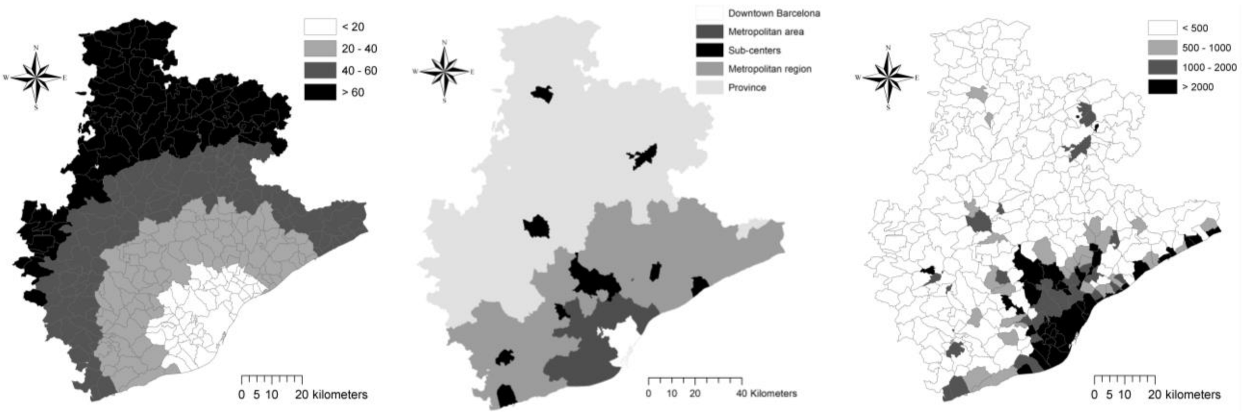
*dummy variables.

Table 5. Loadings of a Multiway Factor Analysis on the first three axes by time interval (only significant coefficients were shown).

Variable	Axis 1	Axis 2	Axis 3
Population density			
1975-1985	0.92		
1986-1996	0.95		
1997-2007	0.97		
2008-2018	0.98		
Migration balance			
1975-1985		0.50	
1986-1996		0.83	
1997-2007		0.85	
2008-2018		0.50	
Total fertility rate			
1975-1985			-0.76
1986-1996			-0.56
1997-2007		0.58	
2008-2018			
Distance from Barcelona	-0.71		
Granollers	-0.58		
Martorell	-0.50		
Matarò	-0.57		
Terrassa	-0.52		
Sabadell	-0.63		
Vilafranca del Penedès			
Vilanova i la Geltrù			
Manresa			
Vic			
Berga	0.59		
Proximity to the sea coast			
Accessibility			0.25
Elevation	-0.75		
Population density			
Migratory balance			
Barcelona metro. area*			
Sub-centres*			
Rest of Barcelona metro.re*	0.59	0.26	
Explained variance (%)	*36.4*	*22.7*	*12.0*

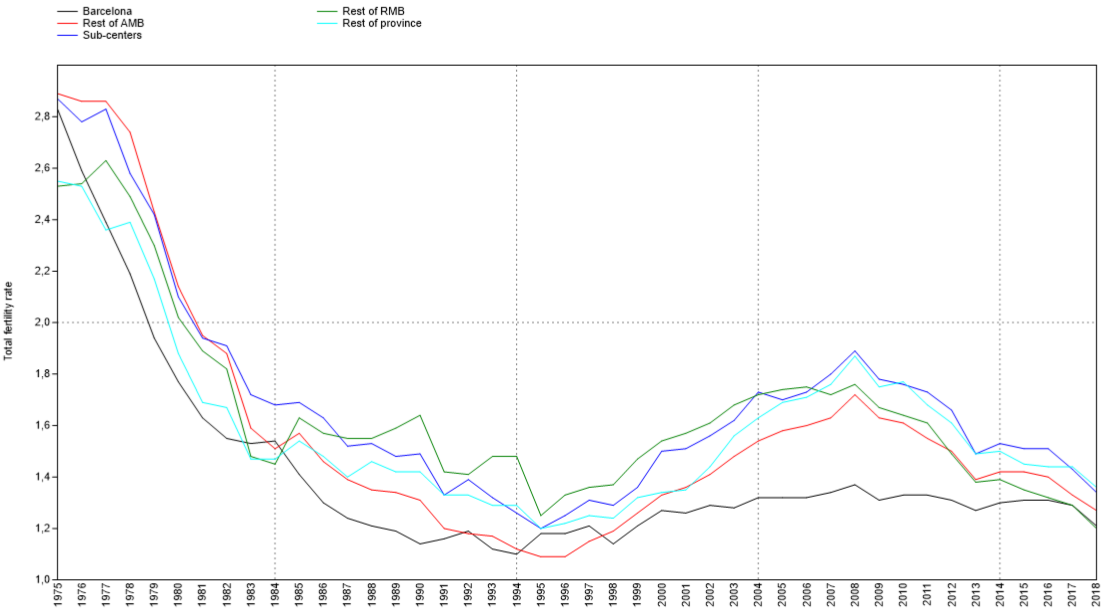
*dummy variables.

Figure 1. Linear distance of each municipality belonging to the study area from downtown Barcelona (left), sub-central municipalities* (middle), and population density map (inhabitants / km^2) at the last census (right).

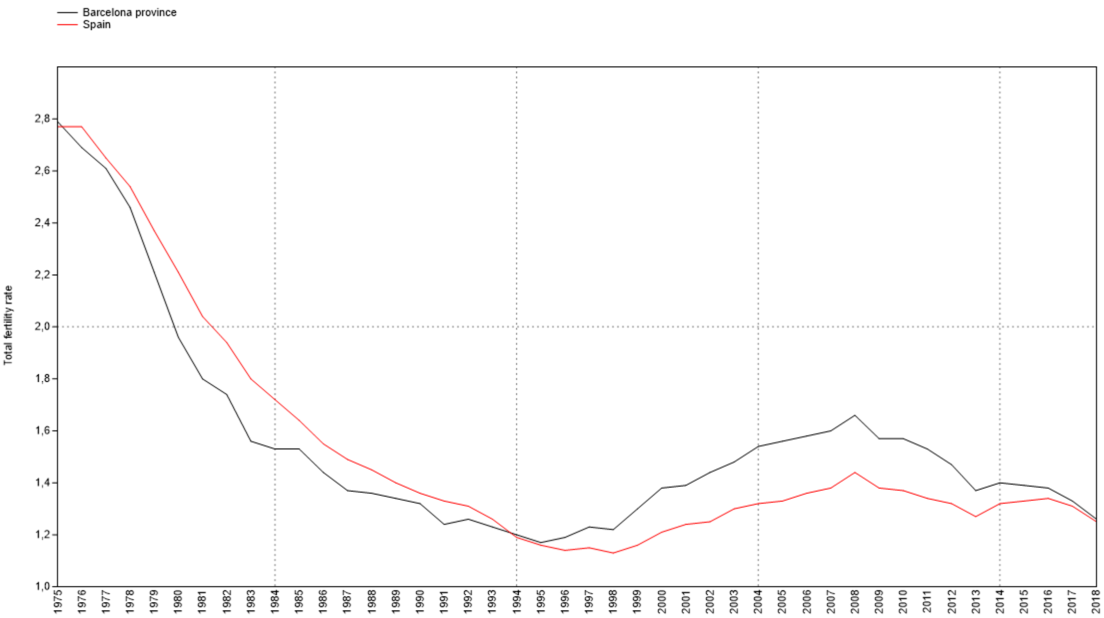


* 'Sub-centres' include seven towns in Barcelona's metropolitan region (Granollers, Martorell, Matarò, Terrassa, Sabadell, Vilafranca del Penedés, Vilanova i la Geltrù) and three towns in Barcelona's province (Manresa, Vic, Berga); please also refers to Table 2.

Figure 2. Total fertility rate in Barcelona province by district (a) and comparison with Spanish fertility by year, 1975-2018 (b).

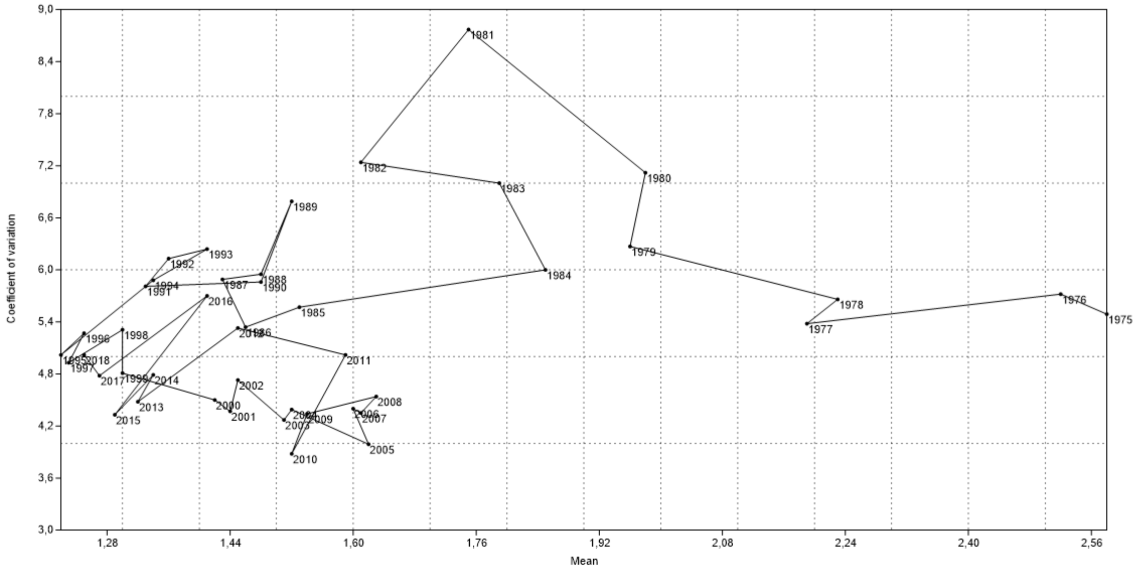


(a)

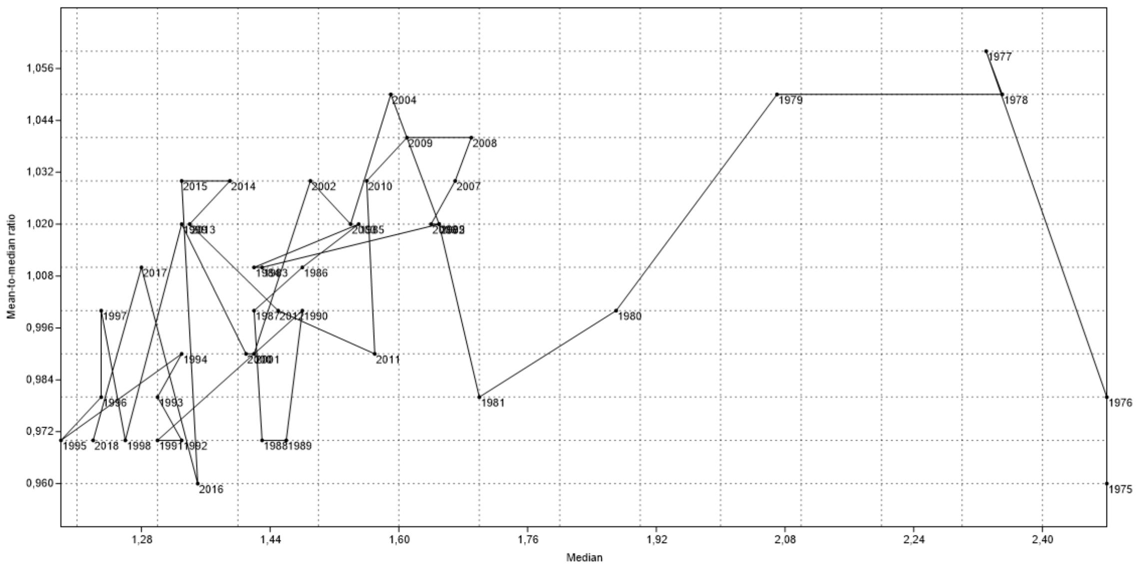


(b)

Figure 3. Relationship between average and coefficient of variation of total fertility rates, municipal-scale (a) and between median and average-to-median total fertility rate, municipal-scale (right) in Barcelona province (left) by year (1975-2018).



(a)



(b)

Figure 4. Spatial distribution of total fertility rate in Barcelona province by time interval, 1975-1985 (upper left), 1986-1996 (upper right), 1997-2007 (lower left), and 2008-2018 (lower right).

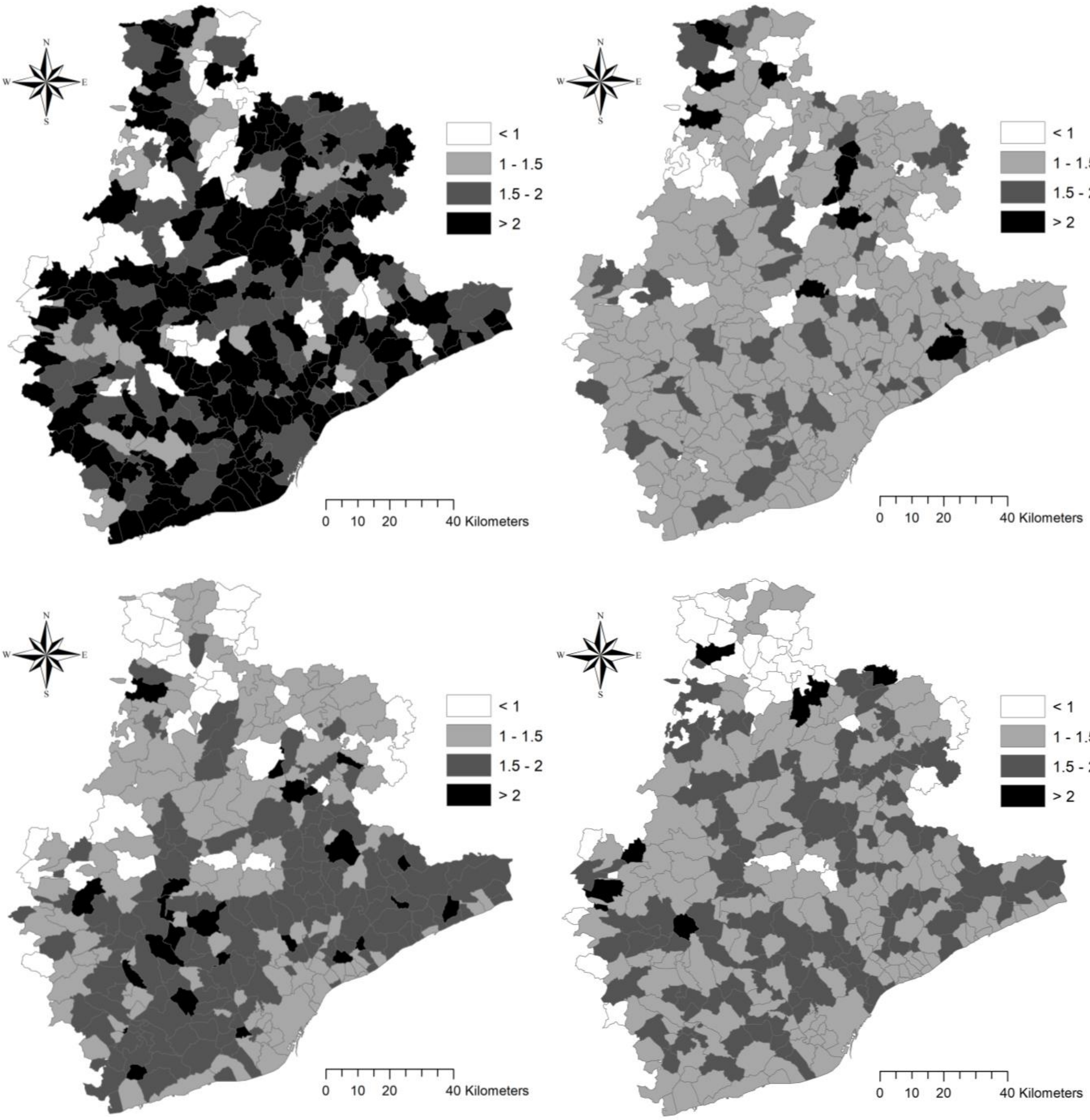
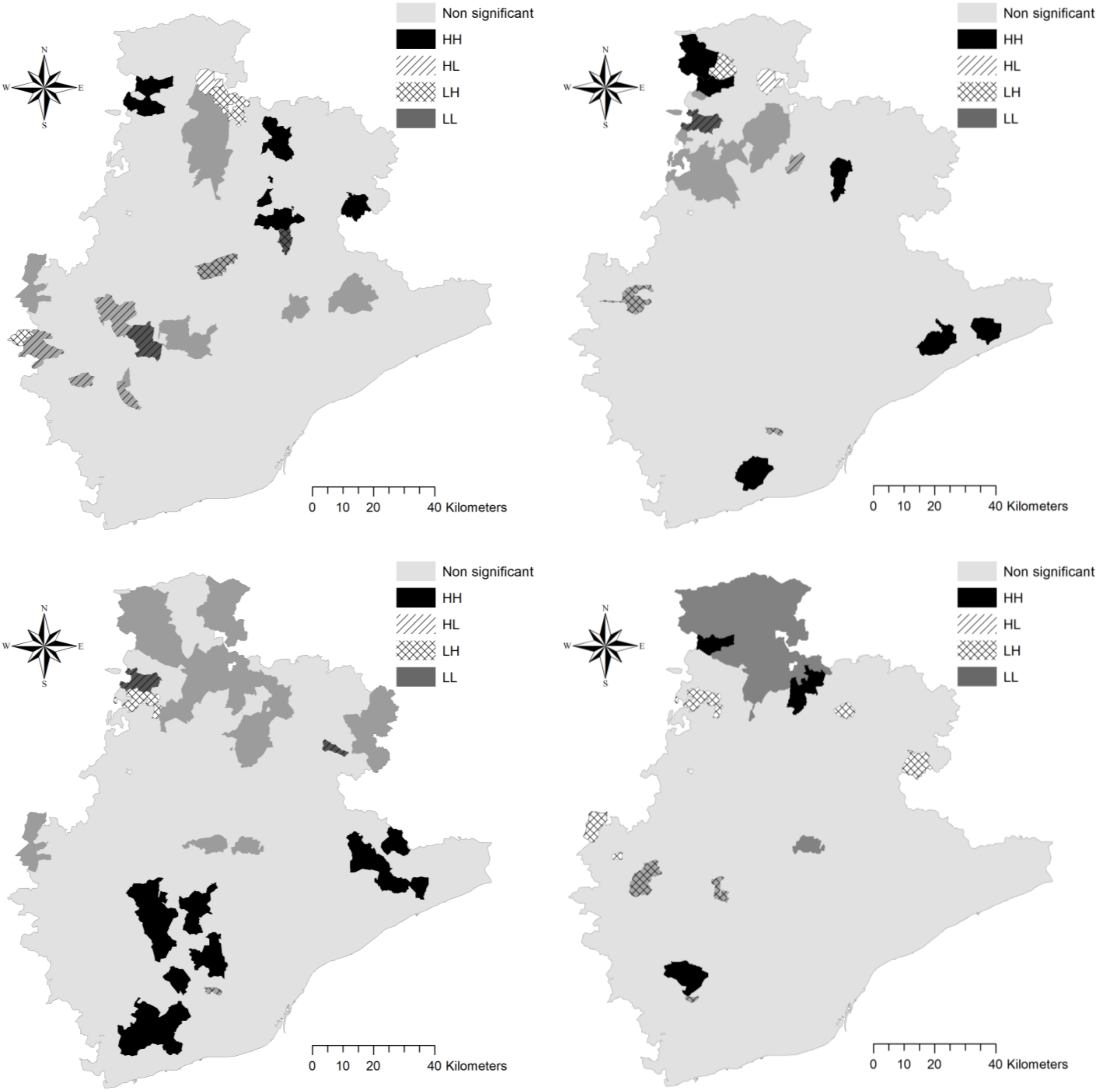


Figure 5. Spatial distribution of the local Moran's z-score of spatial autocorrelation of total fertility rate in Barcelona province by time interval, 1975-1985 (upper left), 1986-1996 (upper right), 1997-2007 (lower left), and 2008-2018 (lower right)*.



* 'HH' and 'LL' respectively indicate a 'High-High' hotspot or a 'Low-Low' cold-spot; 'HL' and 'LH' respectively indicate 'High-Low' and 'Low-High' clusters.