Density-dependent population growth in Southern Europe (1961–2011): A non-parametric approach using smoothing splines

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A wealth of social, economic, historical, political, institutional, and cultural factors have been shown to affect the spatial distribution of resident populations, long-term settlement patterns, and demographic structures on the European continent. However, density-dependent mechanisms regulating population growth remain important drivers of socio-demographic dynamics at both the local and regional levels. In Southern Europe, a paradigmatic region with quite homogeneous population dynamics and urban structures, high within-country variability in the spatial distribution of the resident population and across-country differences in population density outline the distinctive demographic patterns at a regional level. A comparative analysis of the spatial distribution of the resident populations of three representative countries of Southern Europe (Spain, Italy, and Greece) contributes to identifying latent trends and density-dependent mechanisms of population growth over a relatively long time period (1961–2011) at the geographic level of local administrative units (LAUs). An explicit analysis of density-dependent spatial patterns of population growth permits a refined comprehension of socioeconomic mechanisms underlying demographic divides. The annual rate of population increase (or decrease) was non-linearly correlated with population density, highlighting the positive (or negative) impact of density variation on demographic growth when the population is sparse (or concentrated). An improved understanding of the density-dependent mechanisms of population growth contributes to a reconsideration of urban strategies and socio-demographic policies relating to heterogeneous regional contexts.

Keywords:
demographic trends,
density-growth curve,
municipalities,
indicators,
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Introduction

Demographic dynamics, local development, and socioeconomic divides are intimately interconnected issues (Antunez et al. 2017) and worthy of more investigation over sufficiently long time intervals that cover representative contexts at detailed enough spatial levels (Salvati–Gargiulo Morelli 2014). While providing information regarding local development trends, comparative analyses of such trends are relatively scarce for advanced economies and especially so for Europe (Kasanko et al. 2006, Kincses et al. 2014, Oueslati et al. 2015, Salvati–Carlucci 2016). Comparing local-level demographic trends across a continent such as Europe – where individual countries exhibit distinctive characteristics that derive from their intrinsic socioeconomic structure, history, and political/cultural background – is particularly interesting when analysing the latent mechanisms of urban growth (Salvati–Carlucci 2011, Zitti et al. 2015, Varga et al. 2016, Zambon et al. 2017). In this regard, multiple socioeconomic drivers have been shown to influence metropolitan expansion in Europe, including (i) globalisation, (ii) structural change from industry to advanced services, and (iii) accelerating demographic dynamics that are progressively less affected by the natural growth of the population and increasingly influenced by international migration (Haughton 1999, Moos–Mendez 2015, Tóth–Nagy 2017).

With regards to this, a wealth of factors have been demonstrated to shape the spatial distribution of resident populations, long-term settlement patterns, and demographic structures on the European continent (e.g. Duvernoy et al. 2018). However, density-dependent mechanisms regulating population growth remain important drivers of demographic dynamics at both the local and regional levels (Morelli et al. 2014). Local-level population density and the related demographic trends are probably some of the most pertinent variables, for which refined investigation may advance knowledge of the recent evolutions of European cities and regions (Gavalas et al. 2014). Empirical analysis in this field of research may reveal complex socioeconomic transformations and give more precise information on the density-dependent mechanisms of population growth, leading to distinctive models of urban growth and metropolitan expansion (Schneider–Woodcock 2008, Solon 2009, Zambon et al. 2018). A complex urban cycle was observed in Europe in the aftermath of World War II (Salvati 2014). While compact urbanisation driven by internal migration was associated with settlement concentration and high population density, dispersed urbanisation in more recent times stimulated residential mobility to suburban areas (Antrop 2004, Di Feliciantonio–Salvati 2015, De Rosa–Salvati 2016). Suburbanisation influenced metropolitan structures and socioeconomic functions, leading to population declines in central cities (Turok 2004, Bruegmann 2005, Paulsen 2014).

Analysis of relevant indicators of demographic dynamics at a disaggregated enough spatial level may outline recent, latent trends reflecting, for example, increased spatial mobility and preference for large dwellings in peri-urban locations

(Kiochos–Rontos 1999, Rodriguez-Pose–Fratesi 2004, Grekousis et al. 2013). In Southern Europe, a paradigmatic region with homogeneous population dynamics and urban structures, high within-country variability in the spatial distribution of resident populations and across-country differences in settlement density outline distinctive demographic patterns at the regional level (Salvati et al. 2018). In fact, regions of Southern Europe have experienced an intense cycle of urbanisation-suburbanisation-reurbanisation, accelerated by a rapid demographic transition towards lowest-low fertility, higher life expectancy, and immigration (Cuadrado-Ciuraneta et al. 2017).

Density-dependent mechanisms of demographic dynamics (growth or decline) are relatively well-studied in non-human populations (both in animals and plants), and underlie particularly complex regulatory processes (e.g. based on predator-prey relationships and other forms of biological control) at the community level (Mueller et al. 1991, Åström et al. 1996, Waters et al. 2013). For human populations, analysis of the density-dependent regulatory mechanisms of demographic dynamics is relatively more difficult because of the inherent complexity of the underlying background context and the wealth of socioeconomic factors and constraints influencing settlement density. Given the amplitude of recent urban transformations (Petrakos et al. 2005), spatial heterogeneity in local-level, density-dependent population dynamics has been relatively sparsely investigated across regions and countries in Europe (Serra et al. 2014, Pili et al. 2017, Salvati–Carlucci 2017).

Testing density-dependent population dynamics in Mediterranean countries may benefit from the operational definition of the Nomenclature of Territorial Units for Statistics (NUTS) classification system provided by Eurostat, the Statistical Office of the European Commission (European Environment Agency 2006). Considering cities and regions as units of the elementary analysis, a relatively vast amount of data, variables, and indicators is available for the last two-to-three decades, allowing for a proper between-country comparison, as far as basic demographic, social, and economic phenomena are concerned. By contrast, databanks including representative data and variables at more disaggregated spatial levels (e.g. municipalities or local districts) are rather scarce, and often need standardisation, validation, and control procedures (Salvati et al. 2012, Ceccarelli et al. 2014, Lauf et al. 2016). Considering a relatively long time period encompassing the last half century (between 1961 and 2011), the present study illustrates a comparative analysis of population growth derived from national census data.

By adopting municipalities as the unit of the elementary analysis, the impact of density-dependent mechanisms of population growth was investigated at the local level in three Mediterranean countries (Spain, Italy, and Greece) using a non-parametric approach based on spline regression. Integration of basic indicators of demographic change and fluctuations in population density may improve the basic knowledge of the intensity and spatial direction of urban growth, evidencing transscalar dynamics over time (Méndez et al. 2016). Under the hypothesis that countries of Southern Europe present similar dynamics over a sufficiently long time interval (Carlucci et al. 2017), the results of the present study may highlight both internal and external factors shaping local-level demographic growth rates (Colantoni et al. 2016). Assuming that local-level population growth is positively correlated with population density, demographic dynamics were demonstrated to shape spatial divides with distinctive temporal patterns and intensity. In this way, a non-parametric, exploratory analysis of local-level population dynamics may inform strategies of urban development and containment, adapting to different socioeconomic and territorial contexts in Europe (Giannakourou 2005, Munafò et al. 2013, Crescenzi et al. 2016).

Materials and methods

Study area

Urban populations in the Mediterranean region have grown steadily from 89 million inhabitants in 1950 to 258 million inhabitants in 1995, and it is estimated to reach 416 million inhabitants in 2030. Urban populations are concentrated in major European countries like Italy, Spain, and Greece (Table 1). In 1995, urbanisation rates ranged between 59.2% (Greece) and 76.5% (Spain), and are predicted to increase (more or less markedly) by the year 2030 (United Nations 2019). Three countries, representative of the population dynamics in Southern Europe, were considered in this study (Spain, Italy, and Greece). These countries display heterogeneous population dynamics at a local level, different population sizes, and a variable number of municipalities. Italy and Spain were the biggest countries in terms of population size and total area, respectively. Italy and Spain also displayed the highest population density and the highest annual rate of growth over time, respectively. In all these countries, the densest locations coincided with central cities and the associated metropolitan areas, including capital cities (such as Madrid, Rome, and Athens) and regional urban centres of high economic relevance, such as Valencia, Seville, and Barcelona in Spain; Milan, Naples, and Turin in Italy; Salonika, Iraklio, and Patras in Greece. Urban primacy was particularly evident in Greece, since the metropolitan region of Athens has contained more than 30% of country's total population since 1951 (Cecchini et al. 2019).

Table 1

Selected demographic statistics by country

Country	Municipalities (2011)	Area, km^2	Population (2011)	Density, inhabitants/km^2	Annual population growth rate, % (1961–2011)
Spain	8,116	521,841	46,816,010	90	1.06
Italy	8,092	301,365	59,434,413	197	0.35
Greece	1,034	132,033	10,939,727	83	0.61

Spatial units of the analysis

A system of local administrative units (LAUs) introduced by Eurostat was adopted in this study. LAUs are the basic elements of the NUTS classification system, and include territorial units that are representative of local communities. To homogenise multiple country-based definitions of territorial levels of governance, local units were based on two existing spatial levels: (i) LAU level 1 (formerly NUTS level 4), defined for most countries as homogeneous local districts of administrative relevance; (ii) the lower LAU level 2 (formerly NUTS level 5), including municipalities, 'communes', or equivalent local units. LAUs play a key role in official statistics because of (i) large data availability from national censuses and (ii) relevance for the implementation of local strategies. With LAUs being subject to minor changes over long observation periods, Eurostat disseminated and regularly updated a homogenised list of spatial units and boundaries for cross-country comparison. More specifically, this study made use of a collection of population data disseminated by Eurostat and derived from national censuses carried out every 10 years at each LAU-2 unit for six time points encompassing 50 years between 1961 and 2011.

Data analysis

Population data were processed and analysed using spreadsheets to calculate two indicators: (i) population density, that is, the ratio of the resident population in the municipal area (km^2); (ii) annual percentage change in resident population over time (1961–1971, 1971–1981, 1981–1991, 1991–2001, 2001–2011). Scatter plots were used to investigate the relationship between population density and annual growth rate percentage by year and country. Assuming that the spatial variation in population growth rates is dependent on the socioeconomic background context (Morelli et al. 2014, Serra et al. 2014, Pili et al. 2017), the relationship between population increase and demographic density was preliminary analysed in this study using a pair-wise correlation analysis that compares parametric (Pearson product-moment) and non-parametric (Spearman rank) coefficients. Both coefficients range from 1 (the highest positive correlation between two variables) to –1 (the highest negative correlation between two variables), with 0 indicating uncorrelated variables. Significant pair-wise correlations were tested at $p < 0.05$ after Bonferroni's correction for multiple comparisons. The absolute ratio of Spearman to Pearson coefficients by year and country outlines the main type of relationship (linear or non-linear). A particularly high ratio of Spearman to Pearson coefficient indicates a non-linear relationship between demographic density and relative population growth.

A smoothing spline, a sequence of third-order polynomials continuous up to the second derivative (de Boor 2001), was adopted here to construct a smooth curve that best fit local-level population data sets. Smoothing splines were used to explore non-linear, complex forms in the relationship between population density and the annual population growth rate percentage at the municipal level by year and country. An optimal smoothing run by a cross-validation procedure allows performing an estimation of the relationship between demographic variables and indicates a 10-order moving average as an appropriate estimator for all investigated countries and years. In this way, multiple data points at the same X value were collapsed to a single point by weighted average and calculation of a combined standard deviation.

Results

The relationship between population density and relative population growth in each municipality of the three countries investigated here was studied using a non-parametric correlation coefficient (Spearman) compared with a parametric coefficient (Pearson). Spearman rank coefficients were significant and high for all comparisons (Table 2). Moreover, Spearman coefficients were systematically higher than Pearson coefficients for all comparisons. The absolute ratio of the Spearman to Pearson correlation coefficient was particularly high since 1981, indicating that the density-growth relationship became progressively more complex and non-linear over time.

Table 2

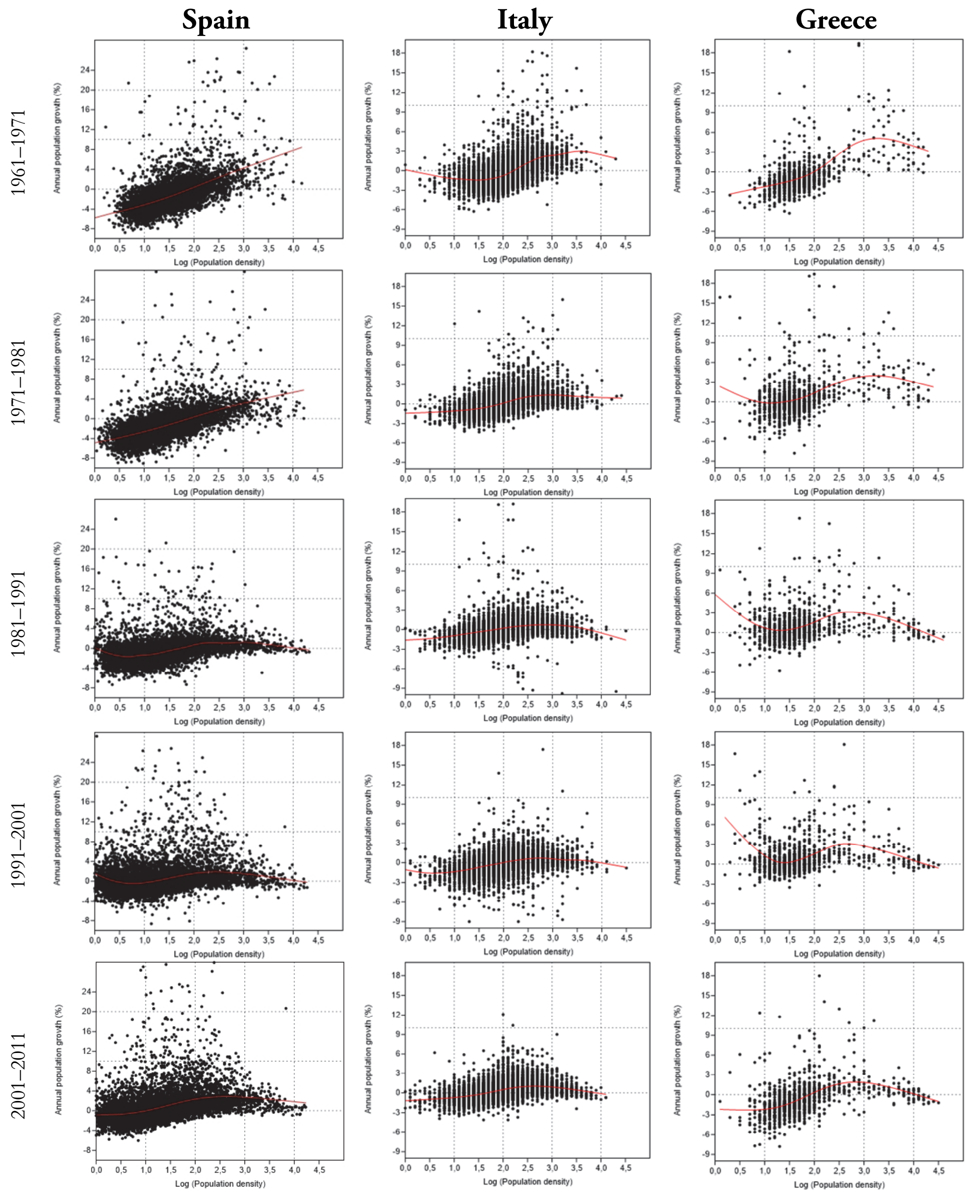
Distribution of Spearman non-parametric correlation coefficients between population density and annual population growth rate percentage in Southern Europe by country and time interval

Country	1961–1971	1971–1981	1981–1991	1991–2001	2001–2011
			Spearman rank correlation coefficient		
Spain	0.613	0.644	0.461	0.287	0.504
Italy	0.553	0.553	0.457	0.463	0.474
Greece	0.484	0.375	0.206	0.217	0.534
			Absolute ratio of Spearman to Pearson correlation coefficient		
Spain	1.30	1.32	2.22	1.95	1.61
Italy	1.21	1.19	2.10	1.26	1.23
Greece	1.18	1.51	1.98	3.44	1.46

Note: All coefficients are significant at $p < 0.05$ after Bonferroni's correction for multiple comparisons, and comparison with the related parametric, linear Pearson correlation coefficient.

Figure 1

Smoothing splines between population density (inhabitants/km², logarithm) and annual population growth rate (percentage by decade) at a municipal level by country and time interval



Results of the non-parametric smoothing splines by country and time interval are illustrated in Figure 1. A non-linear trend – with a more-or-less evident degree of complexity – was observed for all comparisons. Annual rates of population increase in all countries followed an inverse U-shaped relationship with population density, displaying a positive trend at lower densities and a negative trend at higher densities. The breakpoint indicating a shift between positive and negative density-growth relationships was relatively variable over time and space. Threshold densities decreased in all countries, from nearly 3,000 inhabitants/km^2 in 1961 and 1971 to 2,000 inhabitants/km^2 in the following decade. The consequent threshold rate of relative population growth varied from 3%–4% in the first two decades of investigation to 0.5%–1% in the last two-to-three decades.

Variable density-growth thresholds indicate that mechanisms of demographic growth typical of urban areas (i.e. a negative density-growth curve) involved an increasing number of peri-urban municipalities with fewer compact settlements and a lower intermediate level of population concentration. In contrast, mechanisms of growth typical of rural areas (i.e. a positive density-growth curve) were more specifically observed in locations far away from metropolitan regions, with medium-low values of population concentration and higher variability in relative growth rates. Finally, municipalities with very low population densities (< 100 inhabitants/km^2) in depopulated or marginal locations, have displayed a more mixed density-growth relationship, with heterogeneous and spatially variable patterns. In such contexts, demographic growth (or decline) was largely independent from the overall level of density, being influenced by other socioeconomic and territorial factors.

Discussion

European urban areas have grown by 78% in the last half century, with the resident population increasing by 33% (European Environment Agency 2006). Such changes have shaped the structure and functions of peri-urban landscapes around central cities (Russo et al. 2017, Biasi et al. 2015, Kazemzadeh-Zow et al. 2017), leading to spatial disparities and demographic divides (Mykhnenko–Turok 2008). Relatively few studies have compared population trends in European countries at a sufficiently detailed spatial level (e.g. Zambon et al. 2017). The original contribution of the present study lies in a diachronic analysis of long-term demographic dynamics (1961–2011) at the municipal level in three countries of Southern Europe, evidencing similarities and differences in recent urban-rural patterns and testing the hypothesis of a density-dependent population increase over time. In this regard, local-level settlement patterns common to different Mediterranean countries (e.g. population growth along coastal districts and a consequent demographic decline in inland, mountain districts) were assumed to consolidate a metropolitan hierarchy centred on large cities and dispersed urban conurbations in flat, accessible areas (Carlucci et al. 2017).

While identifying specific urban regimes at the local level, the empirical results of this study outline the intrinsic characteristics of each local context and a substantial similarity in the relationship between population density and demographic growth across time and space (Crescenzi et al. 2016). Assuming that population fluctuations reveal how people live and move around (Grekousis et al. 2013), demographic changes are mostly associated with economic agglomeration, being a key factor in land-use change and socioeconomic transformations (Munafò et al. 2013, Haase et al. 2016, Weilenmann et al. 2017). Sequential waves of concentration and de-concentration of urban nodes, together with (i) the expansion of peri-urban and rural/accessible districts, and (ii) the abandonment of marginal rural districts, consolidate demographic divides in high-density and low-density areas (Morelli et al. 2014). All these processes are at the base of a complex density-dependent mechanism of population growth observed in Spain, Italy, and Greece.

While evidencing a moderate divergence in the individual countries' demographic dynamics, results of smoothing splines indicate a generalised, non-linear relationship between population density and growth, with slightly different turning points as far as density and growth levels are concerned. A negative effect of density on relative population growth rates was observed at concentration levels higher than 3,500 inhabitants/km^2, declining slightly over time. The corresponding annual rate of population growth was relatively high in 1961 and 1971 (> 3%), decreasing fairly rapidly in the following decades to 0.5%-1%. This pattern was common to Spain, Italy, and Greece, although with small differences in the shape of density-growth curves.

Such findings are in line with the sequential waves of urbanisation, suburbanisation, and re-urbanisation characterising the post-war urban cycle in Southern Europe (Cuadrado-Ciuraneta et al. 2017). In other words, the density-growth relationship may reflect distinctive urban phases at a country and regional level, reflecting multiple factors of socioeconomic change (Colantoni et al. 2016, Pili et al. 2017, Duvernoy et al. 2018). Demographic dynamics and multifaceted urbanisation patterns – from compact expansion to sprawl – have played key roles in shaping the spatial distribution of resident populations. More specifically, location factors promote distinctive patterns of local development based on population density (Turok 2004). The positive annual population growth rate observed in rural areas (with densities generally below 2,000 inhabitants/km^2) counterbalanced the opposite pattern observed in urban areas. This result outlines a negative relationship between density and growth, likely reflecting congestion externalities and a subtle process of peri-urbanisation, observed since the 1960s and intensifying in more recent decades (Carlucci et al. 2017).

Long-term urbanisation processes in Southern Europe are representative of more general dynamics at the continental level. Consolidation of urban and rural poles, demographic divides along the elevation gradient, and a substantial density-dependent mechanism of population growth are generalised phenomena of interest for urban and regional planning all over Europe (Petrakos et al. 2005). Moreover, a comparative analysis of local-level population dynamics may emphasise the inherent complexity of different European contexts and the importance of a diachronic investigation of demographic processes (Antrop 2004, Serra et al. 2014, Di Feliciantonio–Salvati 2015). Although urbanisation processes tend to vary from country to country, our results indicate that population increase in Southern Europe was influenced by similar forces that should be better characterised in a comparative analysis of long-term demographic trends (Zambon et al. 2018). By reflecting similar regimes in the density-dependent mechanisms of population growth, these factors are more intense in demographically dynamic regions, and can be specifically investigated in specific areas of the studied countries.

Conclusions

Integration of basic socioeconomic indicators, including demographic growth rates and population density, allows identification of (apparent and latent) spatial divides, outlining long-term and more recent socioeconomic trends and their impact on settlement structure and urbanisation patterns. In this line of thinking, a comparative analysis of population dynamics clarifies the role of local contexts when designing and implementing joint strategies for spatial planning and regional development at both the country and continental levels in Europe. Population divides were easily identified at the municipal level, being associated with density-dependent processes of urban expansion, and consolidating the socioeconomic divide in accessible/dynamic regions and marginal/inland districts. In this regard, future research should integrate empirical results of density-dependent regulation mechanisms in biological systems and findings from exploratory analysis of human systems, comparing the results of different statistical approaches and theoretical models. Non-linear modelling and non-parametric statistical techniques considering spatial and temporal dynamics seem to be particularly appropriate to this direction. A refined analysis of socioeconomic contexts resulting from different demographic patterns and processes can also improve the reliability and accuracy of demographic forecasts. In this regard, geo-referenced databases with local-level, up-to-date information encompassing relatively long time intervals, are essential to provide the basic knowledge required to identify spatial regimes of demographic growth and the influence of population density. Results of this study encourage a refined, spatially explicit analysis of population dynamics in Southern Europe aimed at identifying differential patterns of urban expansion under spatially varying socioeconomic conditions and heterogeneous territorial contexts.

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