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Emerging urban centrality: An entropy-based indicator of polycentric development and economic growth

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ABSTRACT

This study moves in the debate on polycentric development in Europe proposing an entropy-based indicator of urban centrality based on local-scale diversity in soil sealing levels. This indicator reflects a progressive transition from a mono-centric and hyper-compact morphology towards polycentric agglomerations, with formation (or consolidation) of sub-centres structurally and functionally distinct from central cities. The proposed approach was tested in three metropolitan regions (Barcelona, Rome and Athens) with the aim to provide a comparative analysis of recent urbanization patterns in European countries affected by rapid processes of urban spillover. The local socioeconomic structure underlying urban expansion was investigated using descriptive, correlation and multivariate analysis of 52 contextual indicators. Results of this study shed light on long-term urbanization patterns in the examined cities, providing evidence of a progressive settlement scattering in Rome and Athens. Early signals of polycentrism were observed in Barcelona. Diversification in the level of soil sealing decreased with the distance from central cities. The article finally debates on the use of composite indexes of diversification in the level of soil sealing when assessing polycentric urban development.

1. Introduction

Urban expansion is inherently related to the production base and the socio-spatial structure of a given region, reflecting territorial complexity, environmental constraints and economic centrality at the same time. Initially concerning the United States, urban dispersion has advanced rapidly in Europe, becoming a debated issue in research, planning and political agendas (Galster et al., 2001; Richardson and Chang-Hee, 2004; Bruegmann, 2005; Kasanko et al., 2006; Orenstein et al., 2014). While being representative examples of compact and dense cities, European urban agglomerations have experienced high rates of land consumption thanks to the sprawled expansion of residential settlements into peri-urban areas (European Environment Agency, 2006). This process has consolidated large conurbations and medium-size town networks (Paul and Tonts, 2005; Schneider and Woodcock, 2008; Salvati, 2014a,b; Serra et al., 2014). Local development has relevant implications in the spatial organization of metropolitan regions, promoting (more or less) marked shifts towards discontinuous urbanization (Tsai, 2005; Turok and Mykhnenko, 2007; Colantoni et al., 2016). Conversely, a spatially-balanced and functionally-polycentric metropolitan structure characterized by population decentralization and coexistence of multiple sub-centres, may positively contribute to urban competitiveness (Phelps et al., 2006; Caruso et al., 2007; Gilli, 2009; Herrschel, 2009; Lang et al., 2009; Fernández-Maldonado et al., 2013; Salvati et al., 2015).

The notion of entropy, traditionally associated with the concept of 'disorder', was first considered by Batty (1974). Entropy has been used largely in the assessment of regional economic systems (Gordon, 2010; Wilson, 2010), with relevant implications in the analysis of patterns and processes of urban growth (Batty, 2010). Cabral et al. (2013) provided a comprehensive definition of "spatial entropy". In recent years, based on the integration of remote sensing, satellite data and geographic information systems, entropy-based indicators such as Shannon diversity or Pielou evenness have been increasingly used to measure sprawl, investigating distribution and concentration of settlements for final assessment of urban sustainability (Yeh and Li, 2001; Joshi et al., 2006; Araya and Cabral, 2010; Batta et al., 2010; Sarvestani et al., 2011; Deka et al., 2012). The notion of entropy has been also

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associated to the social sphere when investigating e.g. the impact of discontinuous urban expansion on local-scale demographic and economic processes of change (Maly, 2000). According to Lee (2011), unbalanced and fragmented socioeconomic contexts are more likely observed in sprawling areas than in consolidated cities. Sprawl patterns reflect social homogenization (or segregation) and loss of community interactions (Le Goix, 2005; Brueckner and Largey, 2008; Arapoglou and Sayas, 2009). Finally, sprawl-driven changes in the use of land have caused negative impacts on rural land, with loss of agricultural and natural areas as a result of dispersed urbanization (Bart, 2010; Wilson and Chakraborty, 2013; Peng et al., 2015; He et al., 2015).

Earlier studies have indicated spatial diversification in the level of soil sealing as a proxy of urban concentration (Munafò et al., 2010). Entropy-based functions have been also proposed to evaluate heterogeneity in composition and spatial configuration of impervious land in European metropolitan regions (Salvati, 2013). Tombolini et al. (2016) have demonstrated that such functions may better identify central cities and sub-centres than approaches considering single variables such as population density/growth or landscape indicators. Based on these assumptions, diversification in the level of soil sealing can be considered a low-level property of complex urban systems, with practical implications in both environmental and socioeconomic fields (Salvati and Carlucci, 2016).

The present study investigates a set of socioeconomic indicators characterizing local contexts with different levels of land-use diversification in three European metropolitan regions: Barcelona, Rome and Athens. Mediterranean Europe has been frequently described as a homogeneous region as far as metropolitan structures and urban morphology are concerned (Leontidou, 1996; Gospodini, 2009; Salvati and Gargiulo Morelli, 2014). Since World War II, Mediterranean cities' expansion resulted in sequential cycles of urbanization, forming polarized metropolitan regions in contrast with urban continuums typically observed in Northern and Western Europe (Delladetsima, 2006; Catalàn et al., 2008; Carlucci et al., 2017; Rontos et al., 2016). Expressing a persistent dualism between compact and dispersed urban models (Colantoni et al., 2015), Mediterranean cities are representative examples of socioeconomic structures developing on traditional services, with sparse economically-dynamic and socially-mixed districts (Couch et al., 2007; Chorianopoulos et al., 2010; De Rosa and Salvati, 2016). Barcelona, Rome and Athens have undergone (more or less) scattered urban patterns reflecting different development paths (Di Feliciantonio and Salvati, 2015). Sprawl has adapted to each metropolitan context in divergent ways, depending on historical, cultural and political issues, and producing distinct socio-spatial models (Salvati and De Rosa, 2014). The notion of entropy is particularly relevant in these contexts as a result of complex and hardly predictable socioeconomic processes (Couch et al., 2007).

Evenness-based indexes contribute to identify scattered urban expansion from polycentric development based on the spatial segregation in the use of land along urban gradients (Encarnação et al., 2013). We used Shannon diversity (H') and Pielou's evenness (J) indexes to assess diversification in the level of soil sealing at the local scale. These indexes evaluate the coexistence of urban layers with different soil sealing intensity (Salvati, 2013), as a result of a mixed and spatially-heterogeneous use of land, typical of cities with advanced and diversified economic functions (Munafò et al., 2010). We hypothesize that the highest values of these indexes are associated to central cities and employment sub-centres hosting dense population, upper economic functions and typical socio-spatial patterns (Salvati, 2014a,b); transitional sprawling areas are supposed to share evenness values in-between urban and rural areas.

2. Methodology

2.1. Study area

We investigate three metropolitan regions in southern Europe: Barcelona, Rome and Athens. These cities present some common characteristics, including a compact morphology, settlement informality and social diversification (Salvati, 2013). These attributes reflect a common phase of deregulated urban expansion encompassing the time interval between the late 1950s and the mid 1970s, determining social stratification and economic homogenization (Garcia and Riera, 2003; Arapoglou and Sayas, 2009; De Muro et al., 2011). The three study areas encompass the European Urban Atlas boundaries identifying the Large Urban Zones of Barcelona, Rome and Athens (European Environment Agency, 2011), respectively coinciding with the following administrative units: (i) the metropolitan regional authority of Barcelona, (ii) the newly appointed metropolitan city authority of Rome, and (iii) the administrative regional authority of Athens.

The Barcelona's metropolitan region covers nearly 3600 km^2 with undulated topography consisting of nearly 25% lowlands, 60% uplands and 15% mountains. The Rome's metropolitan region extends nearly 5300 km^2 with undulated topography consisting of nearly 35% lowlands, 50% uplands and 15% mountains. The Athens' metropolitan region occupies more than 3000 km^2 consisting of mountains bordering the central cities of Athens and Piraeus, three coastal plains (Messoghia, Marathon and Thriasio) and the island of Salamina. Each study area, however, presents different demographic and economic structures: advanced services, including real estate and finance, tourism and manufacturing in Barcelona; tourism, commerce and the public sector in Rome; manufacturing and traditional services, including commerce and constructions, together with the public sector, in Athens (Tombolini et al., 2015).

2.2. Defining the analysis' spatial unit

Taken as administrative boundaries largely used in urban studies, municipalities and urban districts were chosen as the elementary spatial unit in this study (Salvati, 2014a,b). In Spain, Italy and Greece, municipalities are the minimum mapping unit of most statistical surveys and allow matching (and reliable comparisons) with indicators derived from official data sources. A total of 164 and 115 municipalities were considered in Barcelona and Athens, respectively. Rome's metropolitan region was partitioned into 235 spatial units with 121 municipalities and the central municipality of Rome (1285 km^2) in turn divided into 114 urban districts with a size comparable to the surrounding municipalities. Spatial units were classified in 4 categories: 'central city', 'urban area', 'sub-centres' and 'peri-urban area'. The 'central city' class corresponds to the central municipalities of Barcelona and Athens and to the urban districts of Rome that include the historical city (within the "Aurelian Walls") and the surrounding compact built-up area. The 'urban area' class corresponds to the Barcelona's metropolitan area, the Greater Athens' area and the remaining part of the Rome's municipality. Sub-central municipalities were defined in the three areas according to Salvati and De Rosa (2014). Peri-urban areas finally include the remaining municipalities surrounding each city.

2.3. Identifying and mapping impervious land

Impervious land includes buildings, infrastructures and pavement structures such as sidewalks, driveways and parking lots covered by asphalt, concrete, brick, stone and rooftops (European Environment Agency, 2006). The European Environment Agency (EEA) has recently produced a raster map of built-up and non built-up areas including continuous degree of soil sealing ranging from 0% to 100% in a 100 m grid lattice with pan-European coverage (European Environment