The Annals of Regional Science (2024) 72:335–354
https://doi.org/10.1007/s00168-022-01202-1

ORIGINAL PAPER

Trends and new elements in urban hierarchy research: the Greek paradigm

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Received: 3 January 2021 / Accepted: 7 December 2022 / Published online: 12 January 2023

Abstract

Research on shrinking cities shows continuous links between this phenomenon and the process of urban decline, which has been analyzed in many works, especially in Greece. The impact on urban development can be positive, while population growth over time is characterized by the degree of its convergence. The aim of this study is to gain a deeper understanding of the challenge of urbanization in large cities. The sample used in this effort consists of 117 Greek cities with more than 10,000 inhabitants in 1994, using econometric tools to identify settlements using Markov chain theory with data from 1994 to 2020 from the Hellenic Statistical Authority. Using Urban Hierarchy Research (UHR), a significant decline in Greek Urban Concentration (GUC) and a continuous increase in the population of small- and medium-sized cities were found. The Greek urban system is moving toward a distribution characterized by the seeding of relatively large cities. The study aims to open a broader research discussion in the field of spatial econometric applications.

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JEL Classification J11 · R10 · R12 · R23

1 Introduction

In recent years, theorists have debated issues of “urban development” in order to redefine the term and its meaning. At the same time, questions have been raised about the spatial structure and organization of the urban system in a more complex way. In the context of this scientific debate, the “city” as a unit is an important theoretical research tool. Although the definition of the concept of the size of a city is usually population-based, it is formulated according to the research purpose and needs. The concept of urban hierarchy has been one of the most important theoretical tools used by urban sociologists, geographers, and economists, and theories such as those of Christaller (1966), Losch (1954), Reilly (1931), and Zipf (1949), which made use of the size classes of cities in the urban system. However, in recent years, due to rapid urbanization throughout the developed world, experts’ attention has focused mainly on large cities and metropolitan areas. Today, and due to the “globalization effect,” the phenomenon of centralization has increased in relatively few regions with the concept of global cities (Barnes and Sheppard 2010; Robinson 2011; Leitner and Sheppard 2016; Kanai et al. 2017; Sigler and Martinus 2017). Because economic development and urbanization are parallel and interrelated processes, understanding urbanization allows for consideration of economic development (Eaton and Eckstein 1997; Neal 2018; Peris et al. 2018; Verhetsel et al. 2018; Natapov et al. 2018).

Numerous recent studies have focused on demographic change in the southern Mediterranean. In their comparative study of urban hierarchies in the Mediterranean, Schaffar and Catin (2011) show the different demographic trends of cities on the two shores of this ancient sea. Countries on the southern shore are characterized by increasing urban concentration, while those on the northern shore show stability in their urban systems. By comparing the changes in urban hierarchies and GDP levels per inhabitant in the different Mediterranean countries, Schaffar and Catin (2011) confirm the hypothesis of a bell curve of urban dynamics that implies a succession of concentration and deconcentrating phases over time (Parr 1985; Catin and Van Huffel 2004). The pre-urban phase, characterized by transport infrastructure and the absence of agglomeration economies, is followed by a phase of urban concentration in which public infrastructures develop and cities specialize in particular productions, generating a series of localized economies of scale; this concentration process continues until the gradual emergence of agglomeration disadvantages leads to trend reversal and urban dispersion.

This condition is reinforced by the improvement of interregional transport infrastructure, which facilitates the relocation of productive activities to peripheral regions and cities (Catin et al. 2008a, b). Many empirical studies confirm the explanatory and predictive nature of this model despite significant national differences (Brakman et al. 1999, Petrakos 2003; Soo 2005; Gallo and Chasco 2008; Schaffar 2009; Schaffar and Dimou 2012). In planning urban organization and policy, the validity of such a model implies the need to manage second-stage population growth, sometimes disproportionately, in large metropolitan areas whose original structure does not always provide land or public facilities for residents. It seems to be the case that some large Mediterranean metropolises (e.g., Athens, Cairo, Casablanca, Istanbul, etc.) are located in countries that are at the upper end of the bell curve or even at the top. In some countries, such as Egypt or Greece, the demographic structuring of cities requires coordination between specific national economic and planning policies implemented by major cities to show real urban efficiency (Schaffar and Dimou 2012).

In the case of Greece, the policy of industrial activity cannot be separated from the fact that most of the development, over 50%, is concentrated in the Athens metropolitan area (Psycharis et al. 2014). This approach draws the attention of planners and authorities mainly to metropolitan regions, which, due to their demographic size, are often necessary poles for innovation, research, and economic growth (Grossman and Helpman 1991). In this context, the regional density of firms also underscores the importance of various externalities, especially when public facilities are considered. A closer look at the demographics of the country's cities and a more detailed analysis of urban hierarchies over the past twenty years compel us to examine Greece's urban dynamics while understanding the critical priorities of urban planning. Catin et al. (2008a, b) show that the population share of the country's largest city (i.e., Athens) increases relative to the population of other Greek cities until the 1970s. Thereafter, it systematically decreases, implying that the demographic dynamics of large cities such as Thessaloniki (i.e., the second largest city in Greece) diminish in favor of other, smaller Greek cities.

The aim of this study is to analyze demographic trends in Greek cities during the last two decades, using a set of econometric tools developed in studies on urban hierarchies and industrial growth (Black and Henderson 2003; Ioannides and Overman 2003; Bosker et al. 2008; Schaffar and Dimou 2012; Peris et al. 2018). Using an original database for the period 1994–2018, this study shows that urban dynamics in Greece are more complex and less deterministic than modeling based on the normal distribution suggests. Contrary to what is stated by the Greek authorities, there is no tendency of urban concentration during the study period; on the contrary, urban dynamics are fueled by the growth of small- and medium-sized cities rather than by the growth of other, mostly moderate cities, such as Patras or Larissa, implying a process of convergence of the sizes of Greek cities.

Following this study, the second section presents the theoretical approaches to urban growth. The third section provides a descriptive account of the Greek urban system and the evolution of urban hierarchies. The fourth section discusses growth analysis of the Greek urban economy using stationarity tests and calibration of a nonparametric relationship between growth and size of selected cities. The fifth section relies on Markov chains to examine the relative growth of Greek cities. Finally, the last section summarizes the results and discusses the policy implications for urban planning for Greek urban development.

2 Theoretical approaches to urban growth

The study of urban hierarchies and their development occupies an important place in contemporary regional studies. The starting point of this literature is the original work of Zipf (1949) on the rank-size distribution of cities. According to Zipf, the size distribution of cities in a country or region follows a Pareto law; the rank coefficient of this distribution is an elegant and relevant measure of the degree of urban concentration. If this coefficient is low (i.e., with values below 1), an urban system is characterized by the predominant demographic influence of the largest cities. If, on the other hand, it is high (i.e., with values above 1), the population is more evenly distributed among the cities in the system. In many regions, the upper part of the size distribution of cities follows a Pareto distribution in descending order, while the hierarchization coefficient is relatively stable with a value close to 1 (Gabaix 1999; Fujita et al. 1999; Dobkins and Ioannides 2000; Guérin-Pace 1995; Eeckhout 2004; Soo 2005). Under this regularity, Zipf's law (1949) implies that the urban hierarchies of a country or region remain stable over time, regardless of economic changes. According to Krugman (1996), this is a fascinating "urban puzzle" to interpret. The study of urban growth complements previous studies as they address the mechanisms of demographic change in cities based on the origin of urban hierarchies. In this study, we highlight the links between the characteristics of cities and their population growth; we try to identify the circular processes that link the specialization of each city, the presence of localized increasing returns, or the development of its human capital to a continuous and cumulative process of agglomeration of firms and households. Urban growth processes are studied and interpreted in two major theoretical approaches: (i) deterministic growth and (ii) random growth (Dimou and Schaffar 2011; Duranton 2012). According to Duranton and Puga (2013), in the deterministic growth approach, they allow for heterogeneous cities, in contrast to the second approach (i.e., random growth), which considers the homogeneity of cities in an urban system.

Deterministic growth models lie at the intersection of Lucas' (1988) endogenous growth approaches and Henderson's (1988) theoretical constructions of agglomeration externalities. In these models, urban population growth is fundamentally related to the location decisions of firms. The concentration of firms, workers, and economic activities depends on the characteristics of particular urban locations, including advantages such as accessibility through networks of different modes of transportation and other characteristics such as a pleasant climate or advantages arising from the interactions of economic agents. In some models (e.g., Black and Henderson 2003; Rossi-Hansberg and Wright 2007), demographic change is sustained by a range of agglomeration-type externalities and depends on the productive specializations of individual cities. Urban growth is a process that is a continuation of the earlier demographic dynamics of cities. In practice, the explanatory power of these models, which generally reject the validity of Zipf's law, is controversial. The model of Eaton and Eckstein (1997), applied to French and Japanese urban systems, makes it possible to construct stable rank-size distributions of cities based on empirical observations. Using a similar model but allowing for urban heterogeneity, Black and

Henderson (1999) first conclude that the parallel growth of US cities between 1950 and 1990, barring some binding assumptions, shows that the US urban system has a slow tendency toward concentration driven by technological change and the accumulation of knowledge (Black and Henderson 2003).

In contrast to previous approaches that assume random growth, some studies assume that only exogenous shocks can affect the location of agents and also the demographics of cities. These approaches confirm Gibrat's law for cities, according to which the growth of a city at a time t does not depend on its initial size or past demographic dynamics and does not affect its future growth. The size of cities follows a random movement characterized by a sequence of independent and identically distributed shocks and does not converge to a finite distribution. This conclusion implies that there is no optimal city size. Gabaix (1999), Gabaix and Ioannides (2004), and Cordoba (2008) calibrate models of urban growth in which, under certain restrictive conditions such as mobility-constrained households and constant returns to scale, urban growth resembles a stochastic process that depends solely on exogenous, randomly distributed shocks. In these models, at steady state, city size tends to follow a distribution that obeys Zipf's law, i.e., a Pareto distribution with a hierarchy coefficient of 1. At the intersection of these two approaches, some hybrid models allow for both size effects and exogenous shocks (Duranton 2006 and 2007). In Duranton's (2007) model, the source of urban growth is firms' decision to relocate following an exogenous shock, such as a cross-sector innovation or the creation of a new type of good. More recently, Duranton (2014) points to the influence of other factors on growth: the importance of the road network, the quality of amenities or urban development, and job training. The confrontation of all these approaches stems from the existence of an optimal city size. Theories of random growth contradict this hypothesis, assuming that external agglomeration effects are not an explanatory factor for urban population growth; conversely, deterministic models lead to convergence of city sizes under certain conditions. At the practical level, a number of research studies address the evolution of urban hierarchies and the nature of growing cities in different countries and regions, focusing on the convergence of city sizes and the validity of Zipf and Gibrat's laws. These studies rely on different econometric tools (e.g., Findeisen and Sudekum, 2008; Bosker et al. 2008; Schaffar and Dimou 2012; Duranton and Turner, 2012) used in the Greek urban system.

Table 1 Population growth rates in Greece

Period	Total population	Urban population	Increasing of urban population (%)
1960–1970	2.5	4.3	31.7
1970–1980	2.6	4.4	37.4
1980–1990	2.2	4.0	44.5
1990–2000	1.7	2.8	51.5
2000–2010	1.1	1.8	55.6
2010–2020	1.0	1.8	59.6

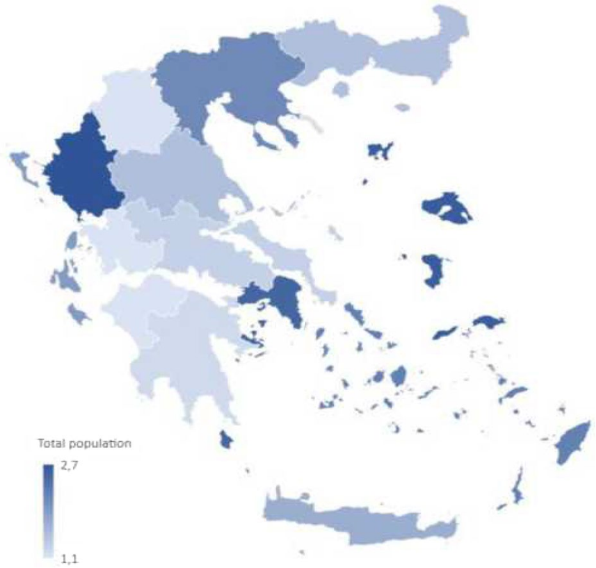

Fig. 1 Greece's total population period per region in graph (2000–2019)

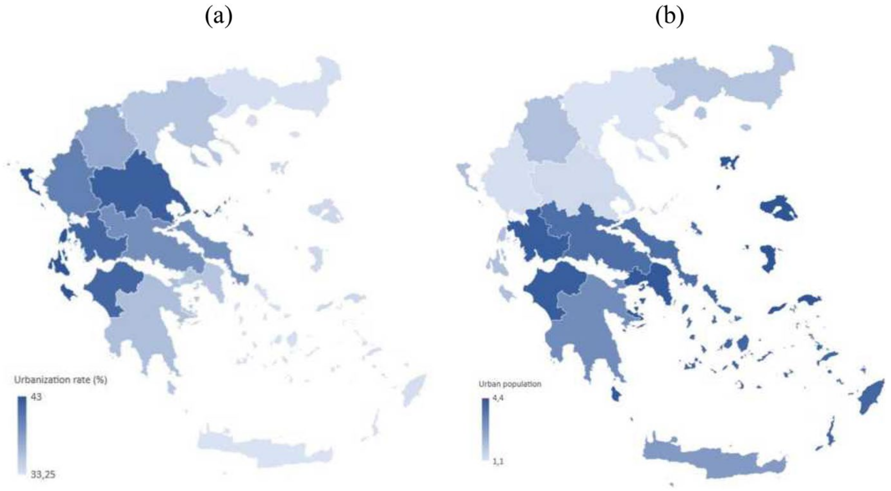

Fig. 2 **a** Greece's urbanization rate (%) per region in graph and **b** urban population. period per region (2000–2019)

3 The evolution of Greek urban hierarchies

After 1960, Greece experienced a sustained process of urbanization: at independence, the urbanization rate was 29%; in 2010, it reached about 60%, ranking Greece's major cities first among the most urbanized countries in Eastern Europe, although still far from European standards (77.5%). Greece's urbanization is driven mainly by two factors: the high birth rate in the middle urban population (i.e., an average of 7.8 children per family) and the massive development of rural areas. It manifests itself in the growth of large urban agglomerations with their suburbs and new medium-sized cities. In the 1980s, the urbanization process slowed down (Table 1), as the birth rate gradually declined and rural–urban migration decreased, while urban unemployment increased between 15 and 20% (ELSTAT, 2013).

In studying the growth and urban hierarchies in Greece, the definition of the city plays a fundamental role. Considering the agglomeration, i.e., the city in its maximum spatial extension, instead of the urban administrative unit, makes it possible to capture the real dimensions of the processes of concentration and dispersion in the city. This option is often problematic, because when the statistical data series for urban administrative units are available, agglomerations are hardly available (Figs. 1 and 2).

The database used in this study comes from the Hellenic Statistical Authority (ELSTAT) and allows the annual population growth between 1994 and 2020. We use here the integration of all neighboring cities and suburbs as agglomerations of the same city, e.g., the cities of "Attica," "Thessaloniki" and "Chania," etc. A question related to the definition of the city is the minimum size of the city. The size distribution of the Greek territory is characterized by the appearance of outer ridges, but they behave differently from the rest of the distribution. Schaffar (2009) also shows that when the sample, including the regions, is significantly increased, the models for ranking the size in the study of the regions are strengthened.

In Table 2, the size distribution of large cities is characterized by a probability of extreme values at the origin of the formation of "fat tails" that differ from the rest

Table 2 Population growth rates in major Greek cities.

Period (2000–2019)	Total population	Urban population	Increasing of urban population (%)
Attica	2.5	4.3	35.25
North Aegean	2.6	4.4	34
South Aegean	2.2	4	33.5
Crete	1.7	2.8	33.25
Eastern Macedonia and Thrace	1.5	1.8	33.5
Central Macedonia	2.1	1.1	35.25
Western Macedonia	1.1	1.9	37.25
Epirus	2.7	1.2	40
Thessaly	1.5	1.3	42.25
Ionian Islands	1.9	1.9	43
Western Greece	1.1	4.2	41.75
Central Greece	1.3	3.8	39
Peloponnese	1.2	3.1	35.75

Source: Greece in Figures, Hellenic Statistical Authority 2000–2019

Table 3 Greek cities with more than 10.000 inhabitants 1994–2018

Urban size	1994	1999	2004	2010
Median	36,570	42,266	46,478	61,325
Average	105,492	115,893	127,196	144,951
Escart deviation	277,135	292,440	308,164	329,716
Maximum size	2,713,169	2,829,079	2,946,440	3,095,922

of the distribution. Schaffar (2009) also shows that the use of rank-size models in studying urban hierarchies is questioned when the sample size increases substantially, including smaller cities.

In the study of Greek urban hierarchies, the “separation” of the distribution at 10,000 inhabitants was made mainly for two reasons: First, this threshold corresponds to the definition of city admitted at the Prague Conference (1966) and used by the Greek Haut-Commissariat du Plan (HCP); second, the Greek demographic statistical series are incomplete for cities with less than 10 000 inhabitants. In the database used, the following data are included: 78 Greek cities with more than 10,000 inhabitants in 2019.

Table 3 provides information on the population size of the Greek cities considered. The mean size is small in 1994 (i.e., 36,570 inhabitants), but it increases throughout the period considered (i.e., it doubles after 17 years). The average size also increases, but less rapidly (i.e., 4.2% per year on average), while the city of Athens remains the largest city throughout the period, although its average annual growth is limited to 2.3%. Table 4 shows the demographic distribution of Greek cities. In 1994, about a quarter of the cities had less than 20,000 inhabitants. Sixteen years later, all of these cities have crossed this demographic threshold.

The evolution of urban hierarchies in Greece is analyzed by comparing the rank coefficient of the size distribution of cities in the period 1994 and 2010. On uses the correction of Gabaix and Ibragimov (2009) for the ordinary least squares (OLS) method when small samples are available (see Eq. 1):

$$\ln(R - 1) = a + p \ln(S) \tag{1}$$

where R is the ranking of a given major city, S represents the population of the city i, and p is the hierarchical coefficient for each major city, representing the Pareto exponent. The Pareto exponent is the ratio of the fractal dimension of a network of cities to the average dimension of city population. Thus, a decrease in the absolute value

Table 4 Distribution of Greek cities by size (1994–2018)

1994		1999	2004	2010
50,000 < Total population < 100,000	0.2735	0.1709	0.28173	0.43826
100,000 < Total population	0.1975	0.2371	0.47252	0.22984
Urban population of 87 cities	9,402,430	10,492,942	10,897,193	9,890,472
Representation of the sample	0.964	0.964	0.964	0.964

Table 5 Rank-size model for Greece 1994–2018

	1994	1999	2004	2010
Constant	11.674 *** (0.0000)	11.371 *** (0.0001)	10.175 *** (0.0000)	12.565 *** (0.0001)
ln(S)	– 0. 973*** (0.0001)	– 0.889*** (0.0001)	– 0.922*** (0.0001)	– 0.892*** (0.0001)
Number of observations	117	117	117	117
R adj	0.961	0.988	0.911	0.903

The critical probabilities are in parentheses

***, **, * correspond to a significance at the 1%, 5% and 10%, respectively

of coefficient p indicates an urban concentration trend. At the same time, an increase shows a more equitable distribution of the urban population between the major cities.

Table 5 shows the Pareto coefficients obtained for the city size distributions between 1994 and 2010. The absolute values of the coefficient increase systematically throughout the period, implying that the Greek urban system is shrinking, and the weight of the largest cities is gradually decreasing in favor of small- and medium-sized cities. The past 25 years were truly unusual in demographic terms, as large cohorts of working-age populations fueled the growth of cities and nations. In the new demographic era, we are likely to see a much more fragmented urban landscape, with areas that are expanding rapidly and areas with stagnant or declining populations. The growth prospects of cities will reflect very different demographic footprints and dynamics, shaped by their local birth and death rates, net inward migration, and net outward migration.

In 2010, the size distribution of Greek cities confirmed Zipf's law. Moreover, the use of the quadratic model of Rosen and Resnick (1980) allows to complete the information provided by the rank coefficient (see Eq. 2):

$$\ln(R) = a + P\ln(S) + e\ln(S)^2 \tag{2}$$

Table 6 Quadratic model for Greece 1994–2010

	1994	1999	2004	2010
Constant	0.945 (0.103)	4.575 *** (0.0000)	8.575 *** (0.0001)	9.545*** (0.0001)
ln(Pop)	1.175 *** (0.0001)	0.475 *** (0.0001)	0.075 (0.0001)	– 0.085 (0.0001)
ln(Pop)^2	– 0.0575 *** (0.0001)	– 0.0575 *** (0.0001)	– 0.0575 *** (0.0001)	– 0.0575*** (0. 0001)
Number of observation	107	107	107	107
RA2 adj	0.964	0.964	0.964	0.990

The critical probabilities are in parentheses

*** ,**,* Correspond to a significance at the thresholds 1%, 5% and 10%, respectively

By R the rank of a city and S its demographic size, if the coefficient $e >$ is 0, the rank-size distribution is convex, meaning that the number of average cities is less than that recommended by Zipf's law.

On the other hand, if the coefficient $e < 0$, the distribution is concave, which means that there are many medium-sized cities whose demographic weight balances that of large municipalities and small cities. Table 6 shows the systematic increase of e between 1994 and 2010, confirming the growing importance of medium-sized cities in the Greek urban landscape.

Several conclusions are drawn: first, the urbanization process slows down between 1994 and 2010; second, urban concentration decreases, which means that the largest agglomerations have less weight in the distribution of cities in 2010 than in 1994; third, the weight of medium-sized cities systematically increases. These conclusions seem to contradict the official "a priori" that Greek planning policy is built on a steady state.

4 Urban growth in Greece: toward a convergence of city sizes

We now focus on Greek urban growth. We attempt to determine the deterministic or random nature of urban growth processes by testing the hypothesis of convergence of city sizes. When city size series have a unit root, the process of city growth is stochastic and the effects of exogenous shocks, which are randomly distributed, have a permanent effect on city demographics. Conversely, when the series does not have a unit root, the effects of shocks are transitory; in this case, city growth is deterministic and may lead to a convergence process at steady state (Schaffar 2010). For panel data with fixed and random effects, a model specification is used that assumes that the size of a city follows a first-order autocorrelation process:

A model specification is used in panel data with fixed and random effects, assuming that the size of a city follows a first-order autocorrelation process:

$$\Delta \ln S_{it} = a_i + \theta_i t + \gamma_i \ln S_{it-1} + \sum_{j=1}^{p} \rho_{ij} \Delta \ln S_{it-1} + \varepsilon_{it}$$

where

- Sit is the logarithm of the city's i population in time t.
- Yt is the first-order autoregressive coefficient.
- αi captures the specificity of each city i.
- θit is the indicative term of the ascending trend, and
- εit is a punctual shock in time t.

The term p corresponds to the number of lagged variables. The null hypothesis (i.e., Ho) is nonstationarity versus the alternative hypothesis (i.e., H1) that the logarithms of the city sizes converge. The alternative hypothesis rejects Gibrat's law for (all) cities and allows for a convergence process toward an optimal size.

Table 7 Results of stationarity tests in first- and second-generation panels

Test	Statistics	Results
Levin et al (2002)	Z_{LL}	– 9.085*** (0.0000)
Im et al. (2003)	Wt	– 17.685*** (0.0000)
Choi (2002)	P	8.575 *** (0.0000)
	Z	– 7.625*** (0.0000)
	L* Model with an intercept and a linear time trend	– 7.625*** (0.0000)
Pesaran (2007)	(Cross-sectionally augmented panel unit root test)–CIPS test Model with an intercept	– 1.625*** (0.0000)
	CIPS* Model with an intercept and a linear time trend	– 1.625*** (0.0000)

The critical probabilities are in parentheses

***, **, * correspond to a significance at 1%, 5% and 10%, respectively

This study draws on the first-generation panel stationarity tests of Levin et al. (2002) and Im et al. (2003) and the second-generation tests of Choi (2002) and Pesaran (2007). The first-generation tests are based on interindividual independence, meaning that the demographic trajectories of the cities are independent. However, it seems logical that such correlations exist in the case of urban dynamics. For example, cities belonging to the same region might be affected by certain common macroeconomic factors or, in some cases, by migration flows out of the city due to their proximity or the presence of critical interpersonal networks among their inhabitants.

The second generation of panel data tests assumes interindividual independence and transforms the role of correlations between individuals, previously considered as confounding parameters, into parameters that enrich the information about the dynamics of the observed variables. Table 7 shows the results in this regard. The first-generation tests (Levin et al. 2002; Im et al. 2003) and the Choi test (2003) do not reject the null hypothesis, implying that Greek city growth corresponds to a random growth process. In contrast, the second-generation stationarity test of Pesaran (2007) Ho rejects and confirms the convergence hypothesis of city sizes. Although these results are contradictory, it seems appropriate to focus on the test of Pesaran (2007). Not only is it more robust, but it also allows for the presence of interaction effects between urban and/or regional macroeconomic conditions and city growth. Admittedly, this hypothesis is not further explored in this study, as it points to the need for economic data that are not yet available at the city or regional level in Greece. However, it opens perspectives for future research.

Table 8 Pesaran cross-sectional dependence test results for variables

	High-income regions	Developing	Full-sample industrial
	CD test	CD test	CD test
C1	(6.93)***	(6.56)***	(7.33)***
C2	(117.8)***	(138.76)***	(217.16)***
C3	(126.83)***	(131.46)***	(215.81)***

CD test statistics in parenthesis

*, **, *** indicate significance level at 10%, 5%, 1%, respectively

Table 9 Pesaran unit root test results for variables

	High-income regions	Developing	Full-sample industrial	Full sample
I(0)	Z[*t*-bar]	Z[*t*-bar]	Z[*t*-bar]	Z[*t*-bar]
C1	(1.457)	(− 1.183)**	(0.320)	(2.081)
C2	(− 0.391)	(2.110)	(3.791)	(2.162)
C3	(− 0.551)	(0.341)	(0.431)	(− 0.061)
I(1)	Z[*t*-bar]	Z[*t*-bar]	Z[*t*-bar]	Z[*t*-bar]
C1	(− 09.051)***	(− 11.161)***	(− 16.891)***	(− 05.613)***
C2	(− 1.183)*	(− 2.891)***	(− 2.103)***	(− 2.003)***
C3	(− 7.891)***	(− 6.183)***	(− 9.872)***	(− 08.053)***

t- statistics in parenthesis. *, **, *** indicate significance at 10%, 5%, 1%, respectively

Table 10 Pesaran cross-sectional dependence test results for cointegration analysis

	High-income CD test	Full-sample industrial CD test	Full-sample CD test
C1	(3.71)**	(7.61)***	(7.21)***
C2–C3	(4.23)**	(6.12)***	(3.11)***

Cross-dependence (CD)—test statistics in parenthesis

*, **, *** indicate significance at 10%, 5%, 1%, respectively

These results can be complemented by the determination of a nonparametric relationship between urban population growth rate and urban size, according to the method developed by Ioannides and Overman (2003). The conditional density of population growth rate is determined by city size.

This function $\hat{f}(g|S=So)$ is the quotient between the joint density $\hat{f}(go,So)$, and the marginal density $\hat{f}$(So) is the logarithm of the city's normalized rate of size S.

Pesaran test (2004) is used to check the cross-sectional dependence among all the variables. First-generation unit root tests are not applied when there is the cross-sectional dependency among the variables. On the other hand, it is seen there is always cross-sectional dependency among the variables which includes only the 3 biggest cities (Table 8).

Second-generation root tests can be used when cross-sectional dependence is observed. The Pesaran (2007) second-generation panel root test is used. The results of the Pesaran (2007) unit root test show that for the high income, all regions except industry, the current account of all cluster groups and both population groups are nonstationary. Cointegration analysis is performed for these groups of regions. The first differences of all variables are also consistently stationary (Table 9). Since the current account balances of the developing regions are stationary, they are not included in the cointegration analysis. C3 is stationary for the entire sample, except for C1 and the industrial regions. It is also not included in the cointegration analysis.

The cointegration tests and estimation methods are selected according to the parameters of homogeneity and cross-sectional dependence. Therefore, cross-sectional dependence and homogeneity must be tested first before cointegration and panel estimates are performed. The results of the cross-sectional test by Pesaran (2004) show that there is cross-sectional dependence for both equations (Table 10).

Second-generation panel cointegration tests are grouped as homogenous and heterogeneous estimators. It is decided to use Gengenbach, Urbain and Westerlund Panel Cointegration (Gengenbach et al. 2016) since there is cross-sectional dependency and parameters are not homogenous.

5 The relative growth of the Greek cities

The interpretation of the intra-distribution dynamics of Greek cities over the 1994–2010 period draws on Markov chains, which have been used systematically to study urban growth processes (Eaton and Eckstein. 1997; Black and Henderson 2003; Bosker et al. 2008; Dimou and Schaffar 2009; Schaffar and Dimou 2012). Following the methodological approach of Le Gallo (2004), we assume that the population of a city is a Markov chain. If its size St is known at a given time *t*, its future size is predicted independently of its previous sizes before *t*. This is a Markov chain. In this process, the probability pij,*t* for a city of size i at time *t* to change to size *j* at a time after $t = 1$ is given by (Eq. 3):

$$\Pr\left(S_{t+1} = j | So = io,\ S_1 = i_1, \ldots, S_t = i_t\right) = \Pr\left(S_{t+1} = j | S_t = i_t\right) \tag{3}$$

The use of Markov chains allows us to understand the dynamics of the size distribution of cities. The transition matrix measures the speed and importance of the growth of cities in the size distribution, while the average lead time matrix indicates the minimum number of years required for a city of size *i* to evolve to size *j*. The Markov chain method requires decomposing the distribution of city sizes into several classes. The—necessarily arbitrary—discretization of the distribution is problematic because it can lead to erroneous conclusions (Quah. 1993). To minimize the bias effect, Lopez-Bazo et al. (1999) or Le Gallo (2002) argue for a homogeneous division into classes with the same individuals. However, when applied to urban systems, such a classification ignores size effects because it either separates small cities belonging to the same class or groups large cities and cities of average size into a final heterogeneous class (Duranton and Puga 2005).

This study follows the approach advocated by Black and Henderson (2003) and Schaffar and Dimou (2012), according to which it is necessary to adopt the partitioning of the distribution while taking into account possible "fat tails," i.e., a concentration of cities with small city size in the classes. Therefore, we divide our sample into five classes with thresholds of 0.18 m; 0.25 m; 0.4 m; m., where m is

Table 11 Distribution of the 117 Greek cities with more than 10,000 inhabitants in 1994

	C1	C2	C3	C4	C5
Interval Sij	< 0.18 m	0.18 m < Sij < 0.25 m	0.25 m < Sij < 0.4 m	0.4 m < Sij < m	Sij > m
% Cities	12.85	23.63	9.21	25.60	28.71

Table 12 Rank and homogeneity tests of Markov's chain

Rang test	Statistics	ddl	*P* value
(Ho) order = 0; (H1)	> 0 Ko = 6978. 953	16	0. 000
(Ho) order = 0; (H1)	> 0 K1 = 5298. 923	78	0. 215
Test homogeneity	*K* = 8328.133	4	0. 533

Table 13 Intra-distributional dynamics of Greek cities 1994–2020

Pij	C1	C2	C3	C4	C5
C1	0. 593 (0.021)	0.072 (0.501)	0	0	0
C2	0. 004 (0.091)	0.893 (0.093)	0.088 (0.093)	0	0
C3	0	0.004 (0.0083)	0. 904 (0.099)	0. 055 (0.009)	0
C4	0	0	0.095 (0.002)	0.973 (0.008)	0.003 (0.007)
C5	0	0	0	0.083 (0.0931)	0. 971 (0.0001)

Standard deviations for transition probabilities are in parentheses

the average size of Greek cities. These groups allow us to obtain relatively homogeneous classes while considering the peculiarities of the distribution, which is characterized by a strong presence of small- and medium-sized cities (see Table 11).

Table 11 shows the weighting of each class according to the original distribution breakdown. The first four classes contain cities smaller than the average size of Greek cities. For example, only class C5 represents cities with more than 105,120 inhabitants and illustrates urban configurations ranging from the "Athens" metropolitan area to smaller cities.

Prior to data exploration using the Markov model, its validity and properties must be evaluated (Bickenbach and Bode 2003). We first attempt to determine the order of the Markov chain by performing a test of the X^2 distribution (Basawa and Prakasa Rao, 1980). We proceed sequentially by testing the hypothesis of a chain of order 0 against the hypothesis of a chain of order 1 or higher. Then we test the hypothesis of order 1 (i.e., the Ho) against the alternative hypothesis of a higher order (i.e., the H1). The null hypothesis (Ho) is rejected in the first test, but not in the second, so we can assume that the Markov chain is of order 1 (see Table 12).

We then investigate the temporal homogeneity of the chain, although the reference period is not very long and a priori not characterized by exogenous structural shocks. We also divide the reference period into two sub-periods, namely (i) before 2002 and (ii) after 2002. Finally, we test whether the obtained transition matrices differ from the matrix obtained for the whole period under consideration.

The null hypothesis (H0): pij(t) = pij for all i, j, states that the transition probabilities between the two partial matrices (t = 1,2) and the total matrix are equal.

Table 14 Intra-distributional dynamics of Greek cities 1994–2020

Pij	C1	C2	C3	C4	C5
C1	0. 593 (0. 021)	0. 072 (0. 501)	0	0	0
C2	0. 004 (0. 091)	0. 893 (0. 093)	0. 088 (0. 093)	0	0
C3	0	0. 004 (0. 0083)	0. 904 (0. 099)	0. 055 (0. 009)	0
C4	0	0	0. 095 (0. 002)	0. 973 (0. 008)	0. 003 (0. 007)
C5	0	0	0	0. 083 (0. 0931)	0. 971 (0. 0001)

Table 15 Time of first passage of Greek cities

Mp.ij	C1	C2	C3	C4	C5
C1	0	2.355. 2	25. 2	125. 2	845.19
C2	4.925. 2	0	12. 2	51	335.24
C3	2.125. 2	1.195.23	0	31.55	195.27
C4	4.922. 2	3.611.2	731	0	103.52
C5	2.225. 2	11.935.2	981	501	0

The du2 test does not reject $H<0$, confirming the temporal homogeneity of the transition matrix (Table 11).

Table 13 provides a measure of the mobility of Greek cities within the distribution, while Table 14 shows the times for the first passage from one class to another, i.e., the number of years it takes a city to change its status and move to a higher or lower class.

Two conclusions emerge in this regard: First, instability decreases with size; the mobility of cities in the first groups C1 and C2 is significantly higher than that of C5, which is quite stable (i.e., 99.7% of cities remain in this group).

At the same time, the first groups represent very small cities compared to the cities in the last group; second, for all groups, upward mobility is significantly higher than downward mobility, which can be interpreted as a first sign of size convergence; however, this shift decreases as we move to higher groups.

Table 15 illustrates the upward dynamics of Greek cities; for example, it takes 15.75 years for a city in group C1 to reach group C2 and 48 years to reach group C3; however, it takes 176.4 years for a city in group C4 to move up to group C5. Conversely, downward mobility is very protracted or impossible.

These tables (i.e., Tables 14 and 15) clearly show the upward mobility of cities in the first groups of the Greek rank and size distribution. Conversely, the conclusions for the upper part of the distribution, which seems to be characterized by parallel growth, are more guarded. Downward movements consistent with the hypothesis of a relief of the large cities, as envisaged by the normal distribution, are not observed in any way. Table 13 compares the original 1994 distribution with the ergodic

Table 16 Initial and ergodic distributions of Greek cities

	C1	C2	C3	C4	C5
Initial state	0. 602	0. 382	0. 162	0. 481	0. 142
Ergodic state	0. 0004	0. 001	0. 044	0. 191	0. 922

distribution, which is in a steady state when all upward or downward movement of cities within the city rank-size distribution ceases.

In case the same procedure is used to select the regions with the highest rate, we find that the results are similar and consistent with the most populous cities in Table 14 as above. In the marginal distribution, some 73% of the Greek regions are in the highest group, while a quarter of them belong to group C4. Greek regions show a long-term tendency to level off from the top, which is accompanied by a specific convergence of city sizes in terms of rank-size distribution.

Table 16 compares the original 1994 distribution with the ergodic distribution, which appears to be in a steady state when any upward or downward movement of regions within the bounds of the region's size distribution ceases.

In the marginal distribution, about 70% of Greek cities are in the highest group, while a quarter are in group C4. Thus, the size distribution of Greek cities exhibits a long-term trend of flattening from the top, accompanied by an inevitable convergence of city sizes. Thus, in steady state, Greece would have many cities of reasonable size in its territory.

6 Conclusion—limitations of the study

In the last two decades, Greek spatial planning policies have focused on managing the development of the country's major cities at the head of "Athens." These policies range from the organization of transport to the management of urban land and the implementation of major infrastructure projects; they find their justification in the hypothesis of a process of urban concentration. This article debunks the previous hypothesis and shows that the country's urban dynamics are not characterized by a process of concentration, but by a sharp increase in small- and medium-sized cities. In particular, on the basis of original data from the Hellenic Republic Statistics Office, which allow to identify agglomerations with more than 10,000 inhabitants for the period 1994–2020 and using a set of econometric and statistical tools from growth studies, this study attempts to reach three sets of conclusions:

First, the evolution of the Greek urban system is categorized by a continuous decline in the degree of prioritization and a decrease in urban concentration.

Second, the Greek urban system is characterized by the strong presence of small cities that nevertheless experience increased growth rates in terms of population size. Up to a threshold of 150,000 inhabitants—which corresponds to the average city size in Greece—urban growth is inversely correlated with city size, which is equivalent to a convergence process.

Third, the prior movement diminishes for the average cities and the largest cities, whose growth has more parallel characteristics. The Markov chains show that a catching-up process takes place in the very long run and the Greek urban system moves toward a distribution characterized by the seeding of relatively large cities.

The results above do not confirm the hypothesis of a standard distribution, even if a phase of concentration rather than deconcentrating of cities is observed. Empirical approaches to the validity of the bell curve usually point to a turning point at a higher GDP per capita than in Greece.

Contrary to the predictions of bell curve theories, no unbundling of metropolitan areas is observed in Greece, whose demographics continue to grow more slowly than those of small- and medium-sized cities. The growth of the latter is not related to the effects of the economic and demographic diffusion of large cities toward a more peripheral, less distant city, but to a direct migration campaign.

The limitations of this work are numerous. First, the period considered may seem short enough to study the urban dynamics of a country. However, in contrast to formerly industrialized countries, where demographic change is much faster in countries such as Greece, urban change processes in these countries are much faster. Consequently, the interactions between cities and regional macroeconomic influences are essential for understanding urban change, as shown by the test of Pesaran (2007). This study could have relied on macroeconomic data available at the city and regional levels; however, such data do not currently exist in Greece. City size is also geographically localized data, which means that Greek urban growth is likely subject to spatial autocorrelation effects. Although Le Gallo and Chasco (2008) and Schaffar (2009) have introduced such effects in rank-size models, their inclusion in urban growth models remains a challenge. This work aims to open broader research perspectives in the field of spatial econometric applications.

Thus, the Greek urban system follows a rather complicated urban change, instead, well reproduced by deterministic models in the lower part of the distribution, size of cities (i.e., the convergence hypothesis), but more controversial in the upper part (i.e., the parallel growth hypothesis). These results point to the need to support the demographic growth of small- and medium-sized Greek cities through appropriate policies. In this regard. Greek planning policies in this regard can go in three different directions: first, regulating the urban sprawl of medium-sized cities and their spatial planning; second, establishing a set of modern urban utilities from water supply to waste disposal, etc.; third, developing well-planned public infrastructures that allow exchanges between these new urban spaces and the rest of the country.

Appendix

The approach developed in this paper may also prove useful for analyzing cross-sectional dependence in nonlinear panel data models such as probit and logit specifications. However, this is an area for further research and is outside the scope of the present work.

Tables 17 and 18 in Appendix present key descriptive data on population growth rates in major Greek regions and in Greek cities with more than 10,000 inhabitants over the period 1994–2018.

Table 17 Population growth rates in major Greek regions

Period (2000–2019)	Total population	Urban population	Urbanization rate (%)
Attica	2.5	4.3	35.25
North Aegean	2.6	4.4	34
South Aegean	2.2	4	33.5
Crete	1.7	2.8	33.25
Eastern Macedonia and Thrace	1.5	1.8	33.5
Central Macedonia	2.1	1.1	35.25
Western Macedonia	1.1	1.9	37.25
Epirus	2.7	1.2	40
Thessaly	1.5	1.3	42.25
Ionian Islands	1.9	1.9	43
Western Greece	1.1	4.2	41.75
Central Greece	1.3	3.8	39
Peloponnese	1.2	3.1	35.75

Table 18 Greek cities with more than 10.000 inhabitants 1994–2018

Urban size	1994	1999	2004	2010
Median	36.570	42.266	46.478	61.325
Average	105.492	115.893	127.196	144.951
Escart deviation	277.135	292.440	308.164	329.716
Maximum size	2.713.169	2.829.079	2.946.440	3.095.922

Funding Open access funding provided by HEAL-Link Greece.

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