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Global city size hierarchy: Spatial patterns, regional features, and implications for China

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ABSTRACT

City size hierarchy and distribution are always at the heart of urban studies, as they have a special ability to reveal the rules of city development and urban system spatial layouts. There is however a data deficiency with regard to city size hierarchy and distribution; in particular, an absence of complete statistics and spatial differences from the global perspective. To fill this research gap, this paper investigates global city size hierarchy based on 2014 data of more than 190 countries and regions by using classic models of "rank-size" rule, the fractal theory and the law of the primate city. We analyzed the spatial patterns, regional features, and implications for China from multi-scale and multi-dimension perspectives. The results show that: (1) There is an obvious pyramid structure of global city size distribution, but differences exist among countries and regions with different economic development types, suggesting a feature of "various types with pyramid dominated"; (2) The primate feature of global city size distribution is not very obvious. However, the primacy ratios of developed countries are much higher than others, and significant differences exist among different regions; (3) The global Zipf exponent and Hausdorff dimension are 0.66 and 1.29, respectively. Cities with middle ranks are in the majority, and the monopoly power of large and super cities is effective to a certain extent, indicating a decreasing concentration tendency in the city size distribution and a convergence trend in terms of relative population size, especially with regard to the medium and small cities; (4) The medium and small cities develop swiftly with limited agglomeration effect of large cities, and Chinese cities would significantly influence global urban progress and spatial patterns. Therefore, developing 780–800 cities will be reasonable for China's urbanization efforts by 2030.

1. Introduction

Cities, as the most concentrated areas of human activities, provide fundamental material conditions for and are the basic spatial forms of modern human life and social economic development. In the past, cities were considered to be independent discrete regions; however, with the continuous expansion of the range of human activities, mutual interactive coopetition among and dependence on cities has greatly enhanced city connections (Choi, Barnett, & Chon, 2006; Czamanski & Broitman, 2016). Propelled by economic globalization and rapid urbanization, many changes within global inter-city links, urban spatial layouts, urban forms and manifestations, and urban functions and organizational structures have occurred. For instance, the size and scale of large cities are expanding, the urban agglomerations are growing rapidly, and more world cities or cosmopolitan cities are springing up (Fang & Yu, 2016; Sassen, 2002). As a result, Urban Hierarchy Systems, consisting of large, medium, and small cities with various size scales and functions, are forming within countries, regions, and the globe. Due to the significant and far-reaching socioeconomic and environmental impacts of the size and spatial structure of urban land (including the human populations and economic activities housed within those urban lands), the city size hierarchy has been a core issue within the urban hierarchy system in the field of urban science.

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Related research on city size hierarchy and distribution can be traced back to the famous Central Place Theory, advanced by German scholar Christaller. Subsequently, studies on the law of the primate city, the Rank-Size Rule, and the Fractal Theory of city size distribution have emerged gradually. In addition, many models and methods, such as the urban primacy ratio (Rosen & Resnick, 1980), Zipf's Law (Newman, 2005), fractal dimension (Batty & Longley, 1994), Gibrat's Law (Eeckhout, 2004), and Rank-Clock (Batty, 2008), have also emerged. Meanwhile, a large number of related studies on city size hierarchy have been completed from various academic perspectives (Berry, 2004; Chen, 2012; Ettlinger & Archer, 1987; Hall, Marshall, & Lowe, 2001; Ioannides & Skouras, 2013; Luthi, Thierstein, & Bentlage, 2013). However, as we enter the 21 s t century, faced with expanding globalization and rapid urbanization, we consider what the characteristics of the global city size hierarchy are now. Does it still follow the classical Rank-Size Rule and the law of the primate city? Are there special characteristics in different regions? What implications does the city size hierarchy hold for developing countries?

In order to answer the above questions and fill in the related academic research gap, this paper aims to explore the law of the global city size hierarchy and its spatial differential features by applying the classic models of rank-size rule, fractal theory, and the law of the primate city to the latest data acquired from more than 190 major countries and regions around the world. The rest of the paper is organized as follows: section 2 provides an overview of relevant literature; section 3 introduces the data sources and methods; section 4 presents the results of statistical and mathematical analysis, specifically multi-scale, multi-dimension analysis; finally, section 5 discusses major conclusions and the application of this analysis in China.

2. Literature review

At the beginning of the 20th century, German geographer Auerbach laid the foundation for one of the major issues in urban science by collecting quantitative data on city size hierarchy and its structure (Gabaix, 1999). Through his research, Auerbach found that the city size distribution within a given territory follows a "Pareto distribution," more specifically, in a given territory, the arithmetic product of a city's population size and its rank in the urban hierarchy system approximately equals a constant (Auerbach, 1913). This concept is also regarded as the rudiment of Rank–Size Law. Since the development of this foundational knowledge, it is widely accepted that city population size distribution obeys the Pareto distribution. However, at the same time, continuous debates, calculations, revisions, and improvements of Auerbach's theory have never ceased. Among these revisions, the most important of them appeared in the mid-20th century, as a scholar named Zipf, conducting research on developed countries' city size distribution, discovered that the frequency of cities with different size and their rank (where the rank is determined by the frequency of occurrence) are connected through a power-law function (Zipf, 1949). In his further developed model, Zipf suggested that the city size distribution not only follows the Pareto distribution but also takes a Pareto exponent equal to 1 (Zipf, 1949) such that an ideal rectangular hyperbolic relationship exists between the city's rank and its size. In this study, Zipf's special form of the Pareto distribution is referred to as "Zipf's Law." Zipf's law has been described as the relationship between the city size and its rank, which is why it is often referred to as the "Rank–Size Law." The Rank-Size Law has been widely used in numerous empirical studies on rank-size distributions of city systems (Anderson & Ge, 2005; Chen & Zhou, 2003; Gabaix, 1999; Giesen & Südekum, 2012). In the 1970s, with the assistance of mathematical description tools from fractal theory, mathematician Mandelbrot studied city size distribution from the perspective of fractal geometry, forming a fractal theory of city size distribution and encouraging innovative research on city size hierarchy (Batty, Longley & Fotheringham, 1989; Shen, 2002; Tan & Fan, 2004). After more than a century of progress, relevant research models of and methods for city size hierarchy have improved greatly. At present, the major models and methods include the city primacy ratio, the four-city ratio, the eleven-city ratio, variation coefficient (Eldridge, 2006), Zipf's Law, fractal dimension, Gibrat's Law, and Rank-Clock (Batty, 2013).

Empirical studies on city size hierarchy and distribution have been conducted at varying scales, including country, region, area, and world. For example, from the country and regional perspectives, Das and Dutt (1993) explored the historical evolution of national and regional city size distributions in India by using Zipf's law and the law of the primate city, showing that the nationwide urban hierarchy system in India developed gradually in accordance with Zipf's rank-size distribution. Hall et al. (2001) studied the evolution of urban hierarchy systems in England and Wales using data from department store retail businesses and multinational corporations. They discovered that important urban centers developed at the expense of small urban centers. Song and Zhang (2002) used Chinese city data from 1991 to 1998 to estimate Zipf's law regression and investigate China's city size distribution and its evolution. Song and Zhang revealed that economic and institutional factors greatly affected the urban system and the patterns of urban growth in China. Lu and Huang (2012) studied the urban hierarchy system in post-reform China from the perspective of innovation capacity, and identified a five-tier hierarchy, led by Beijing and Shanghai, and followed by the capital cities of each province and regional center cities. Based on U.S. census data and metropolitan area statistics, research by Ioannides and Skouras (2013) confirmed in a statistically robust manner that the upper tail of the U.S. city size distribution did fit a Pareto distribution. By exploring interactions between German advanced manufacturing services and high-tech enterprises, Ioannides and Skouras (2013) found that German urban hierarchy and city distribution had significant functional features. Through this research, a non-nested hierarchy with overlapping and *trans*-scalar urban networks started to challenge the traditional view of a nested hierarchy.

Some city size hierarchy studies have also been conducted from a global perspective. By analyzing the city size structure of 38 different countries with distinct characteristics, Berry (1961) suggested that 13 of them showed the rank-size distribution, 15 presented the primate city distribution, and 10 indicated a transition from primate city distribution to rank-size distribution. Using new urban population data from 73 countries, Soo (2005) assessed the empirical validity of Zipf's Law for cities by using OLS (ordinary least squared estimate) and the Hill estimator. This assessment confirmed that the OLS estimates of the Pareto exponent were roughly normally distributed, but those of the Hill estimator were bimodal. Meanwhile, variations in the value of the Pareto exponent were better explained by political economy variables than economic geography variables. Using 41 cases from 35 countries, Benguigui and Blumenfeld-Lieberthal (2007) proposed a new approach for analyzing the city size distribution (CSD). They discovered that apparently chaotic behavior of large cities could affect the preciseness of the distribution model, and, to some extent, the socio-economic processes within large cities had similar effects. Taylor, Firth, Hoyler, and Smith (2010) investigated an inventory of 184 examples of Jacobs's "explosive growth" from 1500 to 2005 within the modern world system. The investigation revealed that city growth spurts were front-loaded in countries' respective hegemonic cycles, that is, some positive correlation