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

Chuanglin Fang [a, b, c], Bo Pang [d], Haimeng Liu [b, c, *]

[a] Xinjiang University, Urumqi, 830046, China
[b] Institute of Geographic Science and Natural Resources Research, CAS, Beijing 100101, China
[c] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
[d] China Film Archive (Chinese Film Art Research Center), Beijing 100142, 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.

* Corresponding author. Institute of Geographic Science and Natural Resources Research, CAS, Beijing 100101, China.
*E-mail addresses:* fangcl@igsnrr.ac.cn (C. Fang), teresalove@163.com (B. Pang), haimengliu@163.com (H. Liu).

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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 existed between a country's power of discourse and its rapid urban development. Derudder et al. (2010) analyzed the world city system and its distribution of power with the help of global airline passenger flows between cities. They found that there has been some modest convergence in the distribution of power in the world city system; moreover, they determined that the mechanism for this convergence was the upward mobility of cities located in the semi-periphery and the East Asian region. With respect to globally operating manufacturing and services firms, Kraetke (2014) used social network analysis to study the global-scale urban hierarchy system. Kraetke's analysis indicated that the network structure of distinct industrial subsectors would influence the global urban system.

These studies and their conclusions demonstrate that city size hierarchy and distribution are core elements of urban geography and urban economy. In addition, these studies indicate that city size hierarchy and distribution is one of the most productive research fields. However, current research areas for these studies are limited to certain countries and regions whose city size hierarchy generally conforms to local characteristics. This is because the urban systems vary within different spatial scales. Very few studies discuss the city size hierarchy and distribution from both the perspective of spatial difference and the perspective of the general principles. To fill these research gaps and explore the general principles of urban systems, we collected the most recent urban data of more than 190 countries and regions, as these necessary statistics had been both limited and difficult to obtain in the past. In addition, this paper ignored the influence of national governance systems within those countries and regions. Therefore, the results could provide useful insights to developing countries (e.g., China) for coordinating spatial patterns of different sized cities and promoting urbanization. Furthermore, multi-scale (global, continental, national, and urban agglomeration) and multi-dimension ("rank-size" rule, fractal theory, and the law of the primate city) analysis were used in this study.

## 3. Data and methods

### 3.1. Data

The definition of a city as well as the standard for establishing a city vary throughout the world. In order to implement our analysis and properly compare data, we adopted the United Nations' (UN) minimum population standard for establishing a city and decided that for this study, the concept of a city includes urban settlements, cities, urban areas, urbanized areas, and metropolitan areas with populations greater than 20,000. Although population data (including the data from the UN) has often been scrutinized, we found, by comparing multiple population statistics, that the data are relatively similar, and, therefore, determined that selecting a certain set of population data will not influence the conclusions of the general principles of city size hierarchy. However, with regard to more significant data differences, we will be consider the UN's as well as the official government's statistics The population data used in this study are mainly from 2014; however, some are from 2012, 2013, and 2015. Assuming that the population of one city could not significantly change over the span of four years, this paper regards all the data as from the same year—2014—such that the data are easily comparable.

The majority of the statistics are from the following: the UN database, the population division of the United Nations' economic and social affairs, citypopulation.de, demographia.com, geohive.com, deagostinigeografia.com, CIA World Factbook, World Urbanization Prospects Reports, the World Bank database, China's Foreign Ministry database, and China's Ministry of Commerce database. Other more detailed data used in this study were found in the online publications and tablets from the U.S. Census Bureau, the Japan Statistics Bureau, the British National Bureau of Statistics, the Spain National Institute of Statistics, the France National Institute of Statistics and Economic Studies, the Italian National Bureau of Statistics, the Norway Central Bureau of Statistics, the Israel Central Bureau of Statistics, North Korea's Central Bureau of Statistics, and the Foreign Investment Country Guide from China's Ministry of Commerce, etc.

From these databases, we obtained the total population, urban population, and urbanization level of more than 200 countries and regions, as well as the population of urban agglomerations with more than 750,000 people, the population of cities with over 10 million people (and their numbers), the population of cities with over 5 million people (and their numbers), the population of cities with over 1 million people (and their numbers), the population of cities with over 0.5 million people (and their numbers), the population of cities with over 0.1 million people (and their numbers), the population of cities with over 50,000 people (and their numbers), and the population of cities with over 20,000 people (and their numbers). Then, using statistical analysis software Eviews 6.0 and OriginPro8.0, we selected data with higher degrees of confidence and better fitness results from approximately 190 major countries and regions to further research.

### 3.2. Methods

#### 3.2.1Rank-size rule exponent calculations

Numerous studies apply the rank-size rule in city size distribution analyses. This rule calculates the estimation of the rank-size distribution exponent typically using a linear regression model. This study applied this rule with the help of Eviews 6.0. The following two perspectives (Zipf's law and Fractal dimension) were used to complete the estimation.

a Zipf's law

According to Zipf's law, the size of a city is proportional to the reciprocal of its rank. Specifically, the product of a city's rank and its population size is a constant equal to the population of the largest city in the country (Giesen & Südekum, 2012), shown as follows:

$$P_r = P_1 \times r^{-q} \tag{1}$$

where, $q$ is the Zipf dimension (hereinafter referred to as "Zipf"), reflecting the concentration of population distribution; $r$ is the rank of a city (sorted according to descending city size); $P_1$ is the size of the largest city; and Pr is the size of a city ranking r.

When $q = 1$, the city size distribution is said to satisfy Zipf's law, indicating that in the urban system, the concentration ratio of population distribution and the dispersion ratio of population are completely equal. This means that a relatively balanced urban population distribution exists. When $q < 1$, it suggests that in the urban system, compared to large cities, urban population concentrates mainly in medium and small cities, that is, the monopoly status of the primate city or large cities is not strong enough and the medium and small cities develop relatively well. When $q > 1$, it means that in the urban system, urban population concentrates mainly in large cities and the development of medium and small cities are relatively insufficient. Moreover, the greater the q, the stronger the monopoly capacity of the primate city. Notably, if $q \to \infty$, there would be only one city in the urban system; if $q = 0$, the size of all cities are the same in the urban system. Empirically, Gabaix and Ioannides (2004) stated that a value in a range [0.8, 1.2] of the exponent may indicate the success of Zipf's law.

b Fractal dimension

With the rise of fractal theory, the traditional rank-size rule can also be expressed from the view of fractal science. To be specific, the product of a threshold city's size and the number of cities above the threshold city's size is a constant (Tan & Fan, 2004), shown as follows:

$$N = A \times \mathrm{r}^{-D} \tag{2}$$

where, $D$ is the fractal dimension of city size distribution, namely the Hausdorff dimension (hereinafter referred to as "Hausdorff"); $r$ is the size of the threshold city; $A$ is the constant coefficient; and $N$ is the number of cities with population greater than the threshold city's size.

When $D < 1$, suggesting that relatively significant differences of urban population distribution exist in the region, the monopoly capacity of the primate city is strong, which means a more rational urban system is still immature. When $D = 1$, it represents that the number of cities in the region amounts to the ratio of the urban population of the primate city and the urban population of the smallest, indicating a well-performing system state of the urban system. When $D > 1$, showing that the number of cities ranking in the middle is in the majority, the city size distribution as well as the whole urban system are relatively balanced and reasonable. Furthermore, when $D = 0$, only one city would exist in the region; when $D \rightarrow \infty$, a convergence would appear, that is, the size of all cities in the region would be approximately the same (Liu, 2013).

*3.2.2Law of the primate city*

As a generalization of a country's city size distribution, Jefferson presented the law of the primate city in 1939. This concept emphasized the relative importance of the largest city, which suggested the degree of concentration of urban development factors in the biggest city in the urban system (Jefferson, 1939). Subsequently, scholars proposed the supplementary four-city ratio and eleven-city ratio for more precise analysis. Therefore, the primacy ratio, the four-city ratio, and the eleven-city ratio are all analyzed in this paper to study the city size distribution from the perspective of the law of the primate city. The expressions are as follows:

$$\text{a. Primacy ratio}: \ S = P_1/P_2 \tag{3}$$

$$\text{b. Four}-\text{city ratio}: \ S = P_1/(P_2 + P_3 + P_4) \tag{4}$$

$$\text{c. Eleven}-\text{city ratio}: \ S = 2P_1/(P_2 + P_3 + P_4 + \ldots + P_{11}) \tag{5}$$

where, $P$ is the urban population size; $P_i$ is the size of the city ranking $i$. For the primacy ratio, $S = 2$ is the ideal value of the city size distribution structure; and for the four-city ratio and the eleven-city ratio, $S = 1$ is the ideal value of the city size distribution structure.

## 4. Results

### 4.1. From the global perspective

By 2012, the total global population had reached 7.049 billion, including 3.704 billion urban people, indicating an urbanization level of 52.55%. The total number of cities with populations larger than 20,000 people was nearly 20,000, among which 28 cities have an urban population of more than 10 million people, 41 cities have an urban population between 5 and 10 million, 390 cities have an urban population between 1 and 5 million, and 546 cities have an urban population between 0.5 and 1 million. With respect to the number of these cities per country, India, China, Japan, Brazil, and the United States held the top five rankings. Generally speaking, a basic pyramid structure existed not only for the global city size hierarchy but also for countries and regions with different economic development types (Fig. 1). Seen from different indices on the global scale, the primacy ratio of global cities was just over 1, while the four-city ratio and the eleven-city ratio were less than 0.4, demonstrating a break from the ideal value. At the same time, the global Zipf was less than 1 and the global Hausdorff was greater than 1.2, suggesting that the number of cities ranking in the middle was in the majority and the dominant capacity of primate cities was limited (Table 1). For countries and regions with different economic development types, the primacy ratios of all the developed countries, all the developing countries, and all the less developed countries were between 1 and 2, while their four-city ratios and the eleven-city ratios were less than 0.6, and the ratios of developed countries were closer to the ideal value. Meanwhile, the Zipfs were all less than 1 and the Hausdorffs were greater than 1.1, indicating that the city size distributions were basically reasonable in the all three categories of economic development types (Table 1).

In addition, according to the Zipf and the Hausdorff of countries and regions with different economic development types, the Zipf and the Hausdorff of the developed countries typically distributed between 0.75-1.35 and 0.7–1.3, respectively; the Zipf and the Hausdorff of the developing countries typically distributed between 0.85-1.5 and 0.6–1.1, respectively; the Zipf and the Hausdorff of the less developed countries typically distributed between 1.0-1.75 and 0.45–0.8, respectively (Fig. 2a, 2b). According to the primate city index, in the developed countries and developing countries, the primacy ratios typically distributed from 1.25 to 5, the four-city ratio typically distributed from 0.5 to 2, and the eleven-city ratio typically distributed from 0.7 to 2. In the less developed countries, the primacy ratios typically distributed within the range of 1.25–7.5, the four-city ratios and the eleven-city ratios typically distributed within the range of 0.6–3.7 (Fig. 2-c, 2-d, 2-e). In addition, most of the distributions showed a basic normal distribution.

### 4.2. From the continental perspective

From the continental perspective, some differences appeared in the city size hierarchy. Nearly all the continents have a basic pyramid structure in city size distribution (Fig. 3). Among these pyramids, Europe and South America presented the most standard pyramid structure, while Asia presented a gourd-shaped structure (Fig. 3). The continent with the least standard pyramid structure was Oceania (Fig. 3).

Seen from different indices, the primacy ratios of all the continents were greater than 1, the four-city ratio and the eleven-city ratio of all the continents were less than 0.72; however, there was still a gap between the empirical values and the ideal ones (Table 2). In addition, except for Oceania the Zipfs were less than 1 and the Hausdorffs were greater than 1.1 (Table 2). These Zipf and Hausdorff values suggest that in Oceania, large cities are dominant, while other continents have a relatively high number of middle ranking cities (Table 2). From the distributions of the Zipf and the Hausdorff, in Europe, Asia, and Africa, the Zipf exponent and the Hausdorff dimension were concentrated between 0.8-1.5 and 0.5–1.25, respectively; in North America and South America, the Zipf exponent and the Hausdorff dimension were concentrated between 0.8-1.35 and 0.75–1.15 respectively; in Oceania, the Zipf exponent and the Hausdorff dimension were relatively dispersed (Fig. 4-a, 4-b). Seen from the distributions of the primate ratios, in Europe, Asia, and Africa, the primacy ratio, the four-city ratio, and the eleven-city ratio were concentrated within the range of 1.25–5,

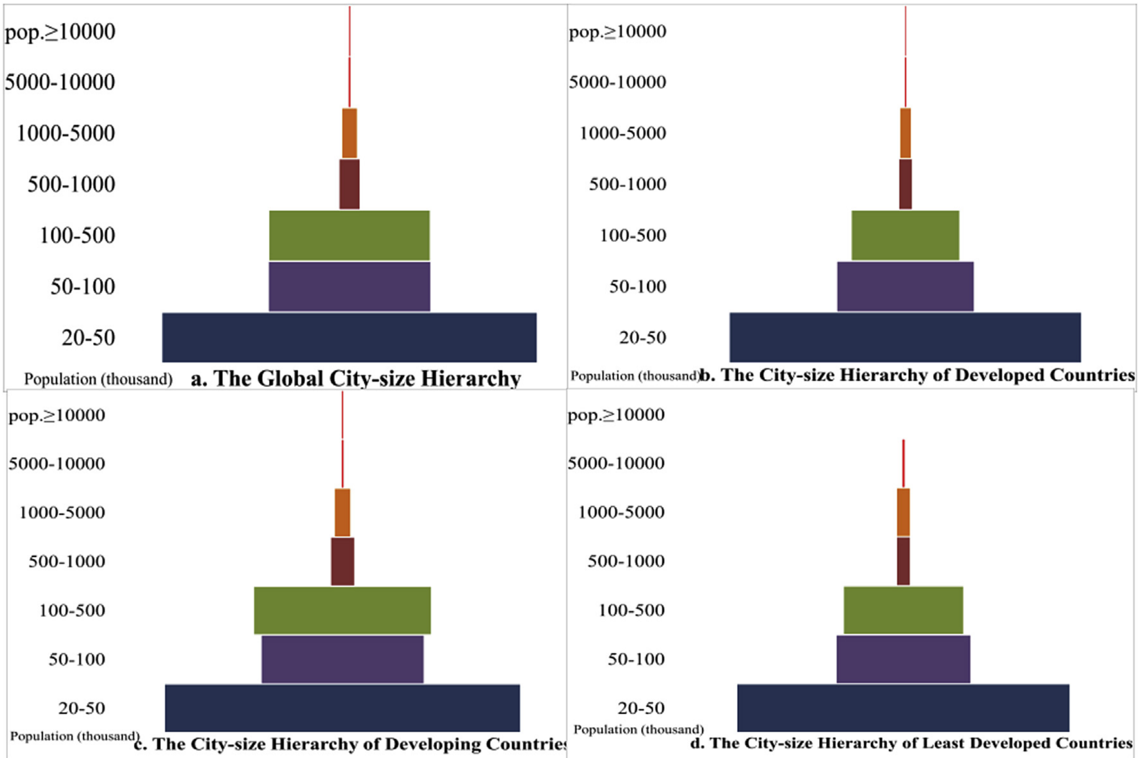


**Fig. 1.** City size hierarchies of the globe and regions of different economic development types.

**Table 1**
The index of the globe and regions of different economic development types.

| Items | Primacy ratio | Four-city ratio | Eleven-city ratio | Zipf | Hausdorff |
|---|---|---|---|---|---|
| World | 1.06 | 0.37 | 0.26 | 0.66 | 1.29 |
| Developed countries | 1.51 | 0.55 | 0.45 | 0.76 | 1.26 |
| Developing countries | 1.06 | 0.37 | 0.27 | 0.69 | 1.25 |
| Less developed countries | 1.29 | 0.47 | 0.46 | 0.83 | 1.15 |

0.5–1.2, and 0.75–3, respectively; in North America and South America, the three primate ratios concentrated towards both the high end and the low end; in Oceania, the three primate ratios demonstrated an essentially uniform distribution (Fig. 4-c, 4-d, 4-e). Overall, the distributions showed normal distribution and some skewed distribution.

### *4.3. From the national perspective*

At the national and regional scale, the primacy ratios of all the countries and regions were concentrated between 1 and 5, their four-city ratios were concentrated between 0.5 and 2.5, and their eleven-city ratios were concentrated between 0.4 and 3, presenting an obvious skewed distribution (Fig. 5-a). Meanwhile, the Zipf exponents and the Hausdorff dimensions of all the countries and regions were concentrated between 0.75-1.5 and 0.5–1.25, respectively, showing a basic feature of normal distribution (Fig. 5-b). After conducting statistical and econometrics analysis, significant diversity in the city size hierarchy was discovered. We identified these diverse hierarchies into the following five major types (Fig. 6, Table 3):

(1) Pyramid-shaped structure. This type covers the most standard pyramid, which includes Switzerland, the United Kingdom, France, Japan, New Zealand, Canada, and Egypt as representatives, as well as the “wide bottom with narrow body” pyramid, which includes Germany, Belgium, Finland, Mexico, India, Brazil, Denmark, Argentina, and Libya as representatives. In total, 84 countries and regions belong to this type.
(2) Olive-shaped structure. This type includes China, Tanzania, Benin, Lebanon, Indonesia, and Nigeria as representatives. In total, 16 countries and regions belong to this type.
(3) Gourd-shaped structure. This type includes Malaysia, Belarus, Kazakhstan, the Philippines, Bolivia, Austria, Italy, Cuba, and Niger as representatives. In total, 24 countries and regions fall into this type.
(4) Inverted T structure. This type includes Fiji, Rwanda, Tajikistan, Yemen, Dominica, Malawi, and Mongolia as representatives. In total, 16 countries and regions fall into this type.
(5) Other types. I-shaped structure, which includes Oman, Slovenia, Panama, Djibouti, and Guyana as representatives (with a total of 19 countries and regions). Linear-shaped structure, which includes Singapore, Equatorial Guinea, and Malta as representatives (with a total of 34 countries and regions). T-shaped structure, which includes two countries, South Sudan and Mauritius. ±-shaped structure of Kuwait. Inverted-I structure of Bahrain.

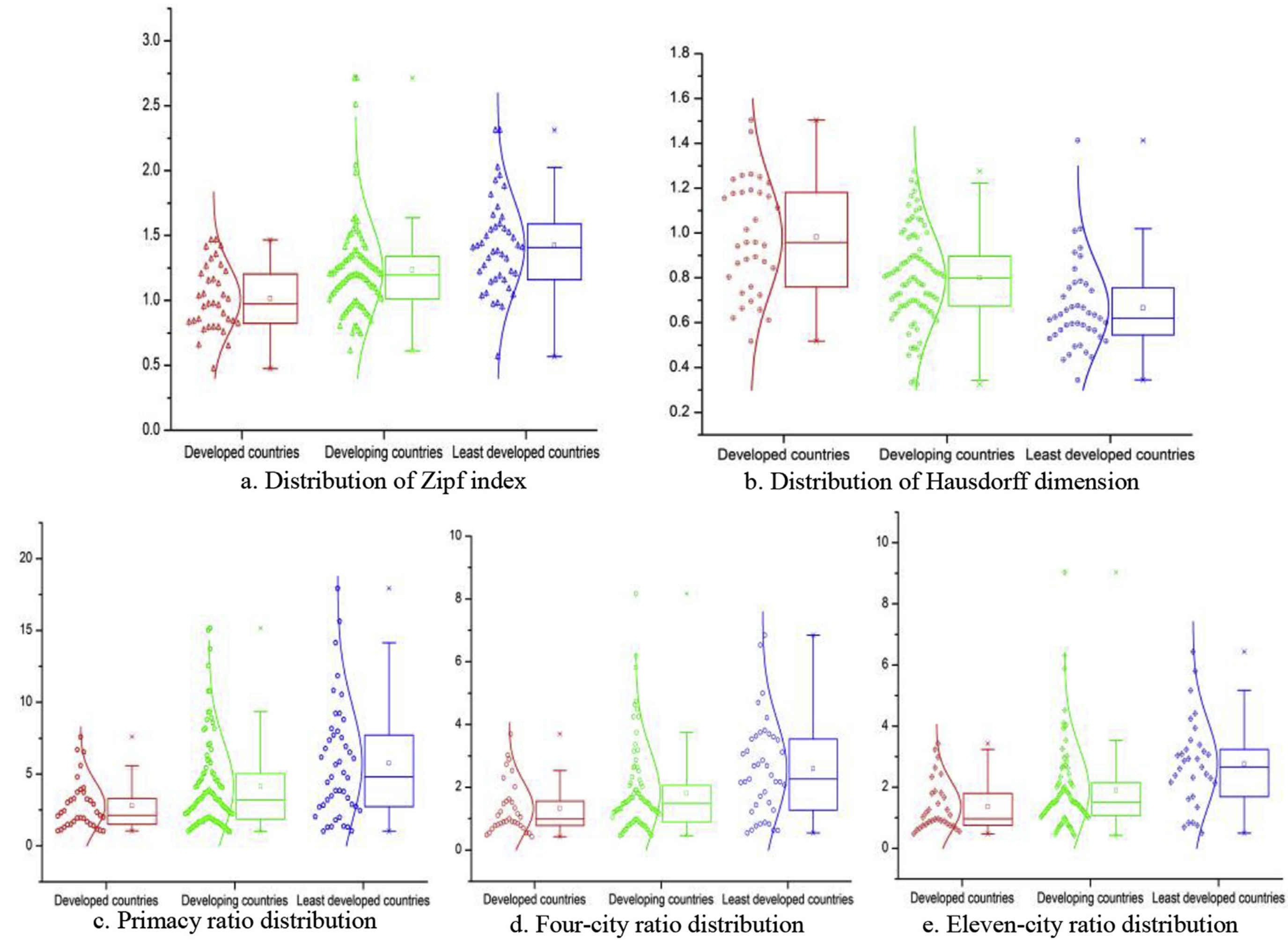


**Fig. 2.** Distributions of index of countries and regions with different economic development types.

### *4.4. From the urban agglomerations perspective*

Since the early 1950s various features of cities, specifically their geographical locations and social economic radiation abilities, enabled cities to increase their populations, resources, capital, and information. These changes unleashed the transformative power of urbanization, facilitating the shift to a new form of city development—urban agglomerations. Driven by the rapid development of global urbanization, cities or urban localities that were functionally or geographically linked gradually fused together and agglomerated, growing as closely related regions. Subsequently, these cities would form mature urban agglomerations, markedly increasing the number of urban agglomerations. Based on the size of global urban agglomerations, before 1970, the world had only two megacities—Tokyo and New York; however, by 2011, at least 359 million inhabitants were living in urban agglomerations around the world.

While Tokyo, the capital of Japan, was still the most populous urban agglomeration with about 37 million urban inhabitants, it was followed by some notable urban agglomerations with more than 20 million urban inhabitants, namely, Delhi in India, Mexico City in Mexico, New York in the United States of America, Shanghai in China, São Paulo in Brazil, and Bombay in India. Based on the number of global urban agglomerations that appeared between 1950 and 2011, urban agglomerations with more than 20 million inhabitants increased from 0 to at least 7, with an average increase of one 20-million scale urban agglomeration per decade. During this same period, urban agglomerations with more than 10 million inhabitants increased from 2 to at least 23, with an average increase of about three 10-million scale urban agglomerations per decade; urban agglomerations with populations ranging between 5 and 20 million inhabitants grew steadily with an average increase of about 7 per decade; urban agglomerations with populations ranging between 0.5 and 5 million inhabitants developed rapidly with an average increase of 98 per decade, among which urban agglomerations with populations ranging between 1 and 5 million increased with an average number of 55 per decade, and urban agglomerations with populations ranging between 0.5 and 1 million increased with an average number of 64 per decade.

With respect to the temporal and spatial variations, to begin, most of the large urban agglomerations (urban areas with more than 750,000 inhabitants) were concentrated in the northeastern United States and Western Europe. However, after stepping into the new century, large urban agglomerations have been expanding to the east and west coast of the United States, the Caribbean coast of North America, the southeast and northwest of South America, the west of Africa, the east and south of Asia, and almost the whole west and center of Europe (Fig. 7). Notable urban population blooms are represented by both the size and number of large urban agglomerations in the east and south of Asia, as countries such as

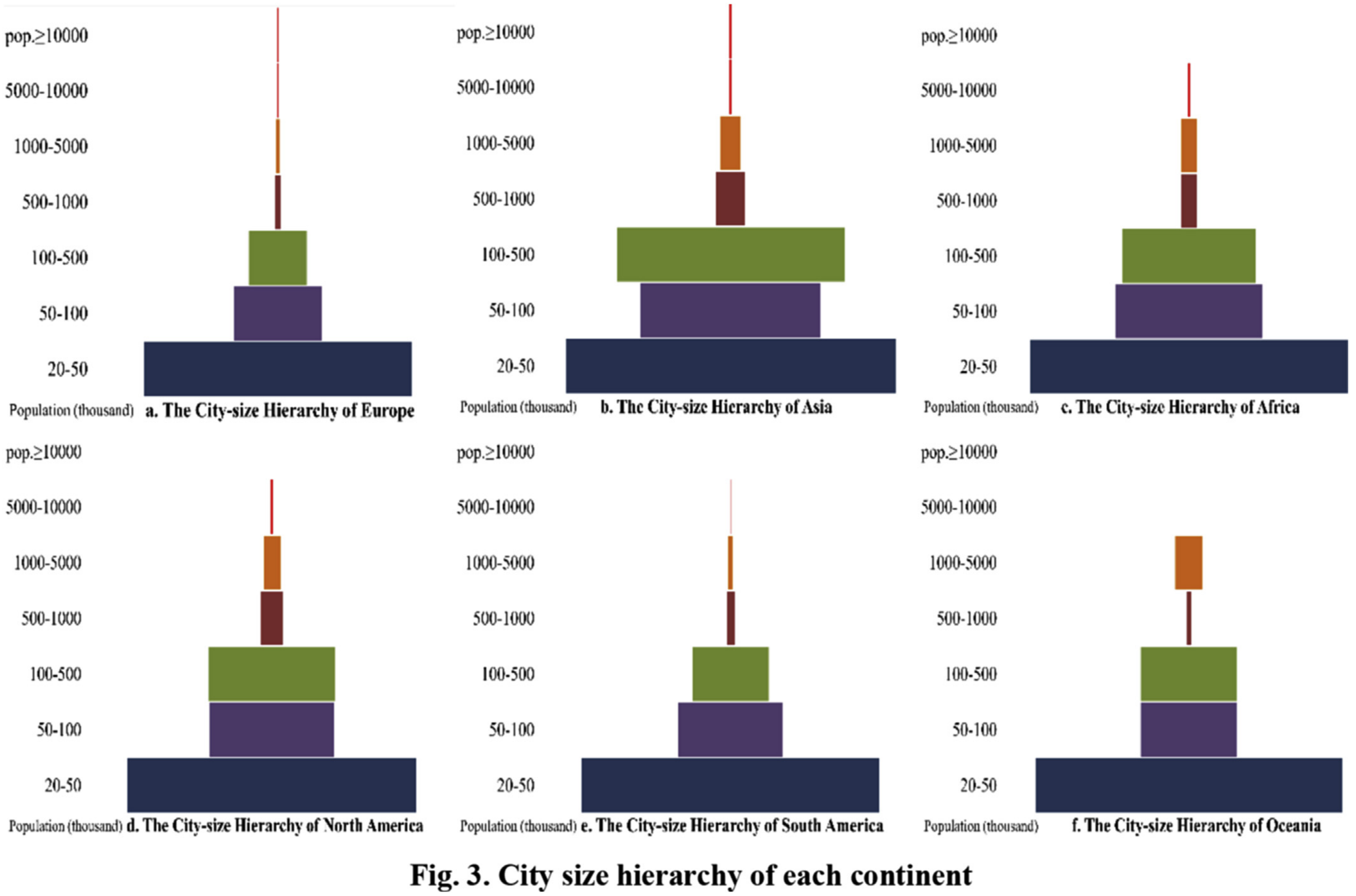


**Fig. 3.** City size hierarchy of each continent.

**Table 2**
The indices of each continent.

| Continents | Primacy ratio | Four-city ratio | Eleven-city ratio | Zipf | Hausdorff |
|---|---|---|---|---|---|
| Europe | 1.13 | 0.50 | 0.55 | 0.74 | 1.32 |
| Asia | 1.06 | 0.38 | 0.29 | 0.71 | 1.19 |
| North America | 1.51 | 0.70 | 0.61 | 0.89 | 1.11 |
| South America | 1.45 | 0.58 | 0.56 | 0.84 | 1.17 |
| Oceania | 1.05 | 0.54 | 0.72 | 1.10 | 0.86 |
| Africa | 1.33 | 0.48 | 0.41 | 0.79 | 1.16 |

Japan, China, and India led the world urban agglomerations rankings list. From the perspective of the varying city size hierarchy index, the city size hierarchy of global large urban agglomerations has developed into the basic pyramid structure over a very long period, and is currently developing into a more flat pyramid structure. As illustrated in Fig. 8, the primacy ratio of global urban agglomerations has always been greater than 1 and increased until the ideal value reached 2.02 in 1990, and, subsequently, it fell toward 1. This suggests that the global population flowing to individual super-large urban agglomerations before 1990 increased gradually, but the trend began to decrease after 1990. The four-city ratio, the eleven-city ratio, and the Zipf exponent of global urban agglomerations have been consistently less than 1. The Zipf exponent has decreased and continues to fall; at present, it has dropped to near 0.5. Meanwhile, the Hausdorff dimension of global urban agglomerations has been increasing gradually along an elongate S-curve, holding values greater than 1.5 since 2000 (Fig. 8). It indicates that the population distribution of global urban agglomerations tend to be more balanced, and the attraction of the small and medium-sized urban agglomerations gradually strengthened.

## 5. Conclusions and discussion

### 5.1. City size hierarchy around the globe

On a global scale, there is an obvious pyramid structure of global city size distribution, meaning that the number of medium and small cities is greater than the number of large and super cities. This structure can be considered a relatively well-structured city size hierarchy. However, differences do exist among countries and regions with different economic development types. According to the calculations, the pyramid-shaped structure appears in the vast majority of the developed countries, like Switzerland, Germany, Britain, France, Denmark, Japan, and Canada, in most of the developing countries, like Argentina, Egypt, Romania, India, and

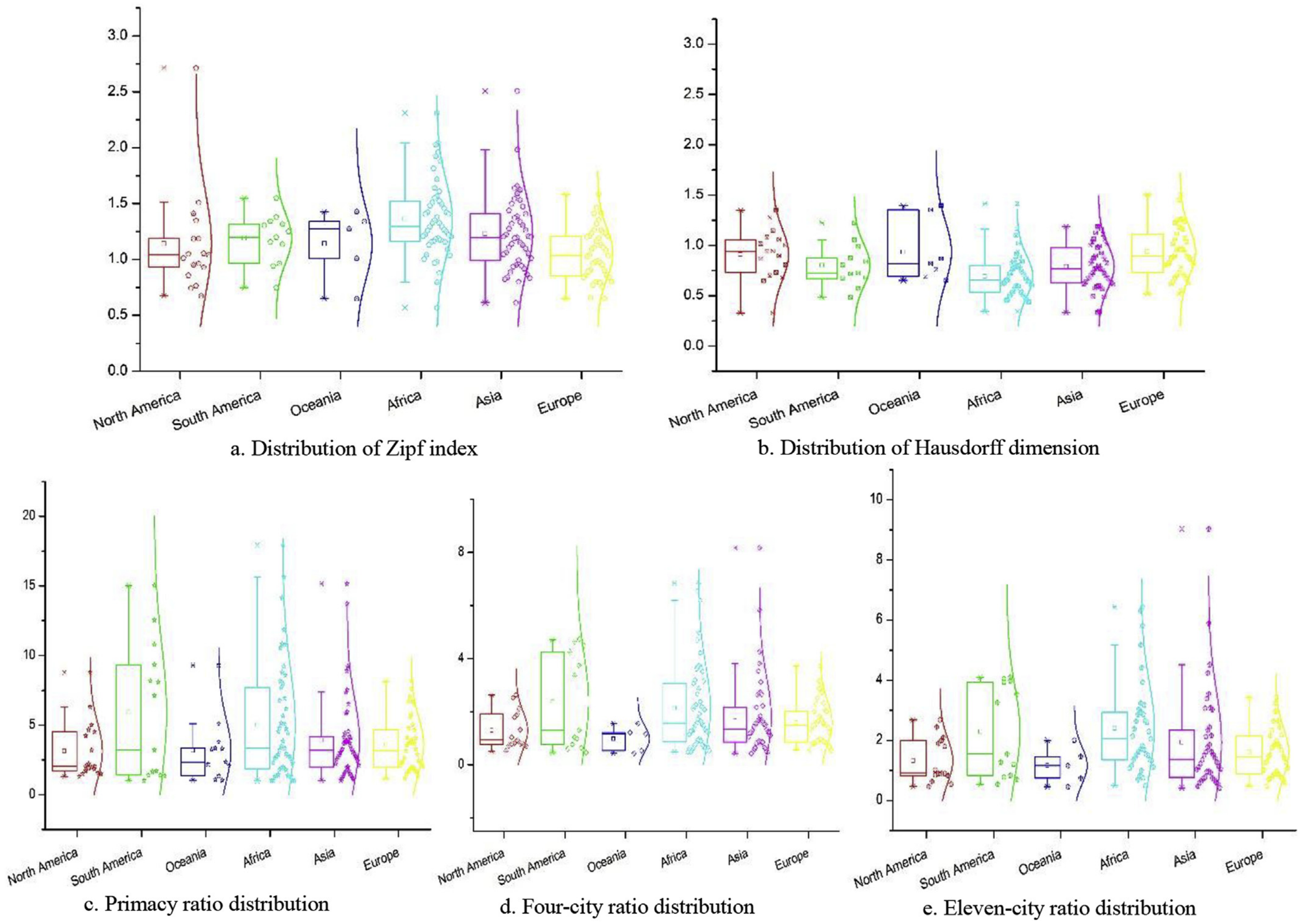


**Fig. 4.** Distributions of indices of each continent.

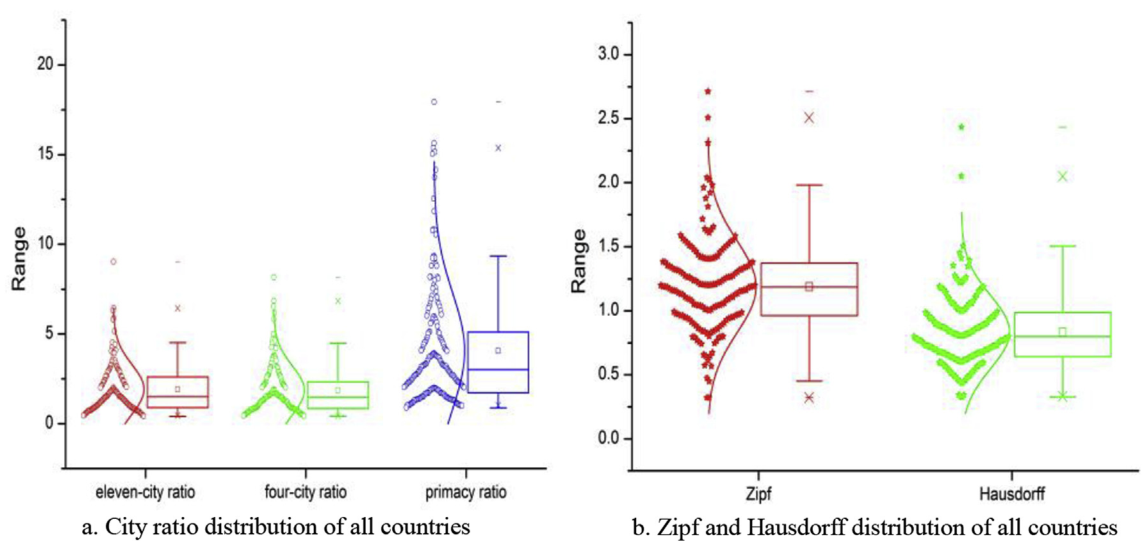


**Fig. 5.** Distributions of index of all countries and regions.

Brazil, and in some of the least developed countries, like Ethiopia, Zambia, Afghanistan, and Eritrea. The olive-shaped structure appears in some developing countries, like China, Indonesia, Paraguay, Turkmenistan, and Guinea, in some least developed countries, like Angola, Mozambique, and Tanzania, and in specific developed countries such as South Korea. Countries with the gourd-shaped structure include some developing countries, like Cuba, Belarus, Kazakhstan, Kenya, Peru, Jordan and Lithuania,

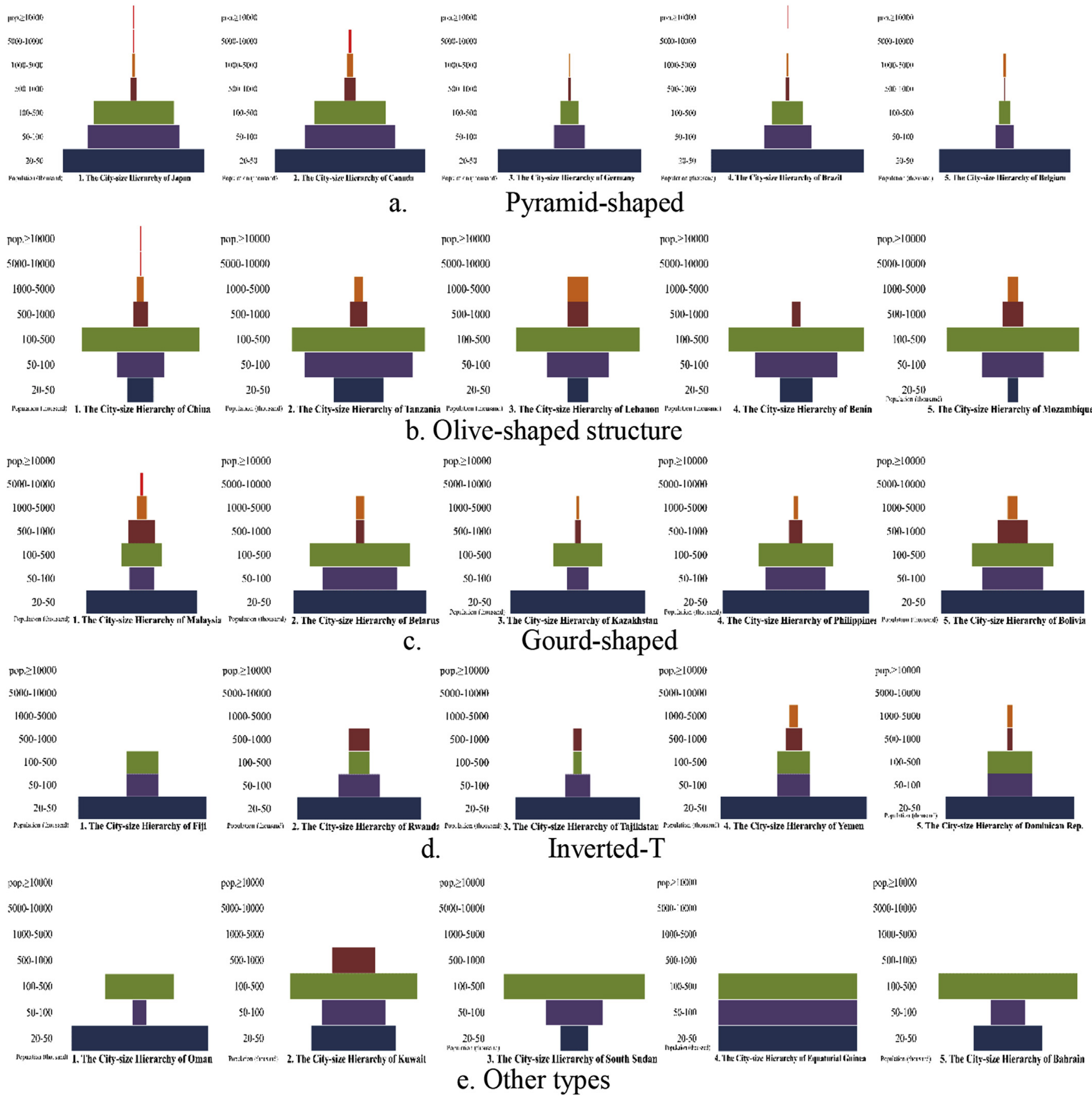


**Fig. 6.** City size hierarchy of typical countries and regions.

specific developed countries, like the United States, Austria, and Italy, as well as some least developed countries such as the Central African Republic and Niger. As to the inverted-T structure, besides some least developed countries, like Rwanda, Liberia, and Yemen, specific developing countries like Mongolia, Armenia, Tajikistan, and the Democratic Republic of Congo are included. Therefore, it is observed that overall, the vast majority of the developed countries present a pyramid-shaped structure with more stable city size hierarchies, while most of the developing countries show various structures including the pyramid-shaped structure, the olive-shaped structure, and the gourd-shaped structure, suggesting a shifting trend of city size hierarchies. On the other hand, the city size hierarchies in the least developed countries are more diverse, besides the pyramid-shaped structure, the olive-shaped structure, the gourd-shaped structure, and the inverted-T structure, the I-shaped structure and the T-shaped structure also exists, indicating that there is great potential for altering and developing the city size hierarchy in those countries. In general, the global city size hierarchies are featured with "various types with pyramid dominated."

### 5.2. The primate city around the globe

According to the law of the primate city, when the city size distribution of a given region is under perfect conditions, the ideal

**Table 3**
Calculation results of city size indices of major countries and regions.

| Name | Primacy ratio | 4-city ratio | 11-city ratio | Zipf | Hausdorff | Name | Primacy ratio | 4-city ratio | 11-city ratio | Zipf | Hausdorff |
|---|---|---|---|---|---|---|---|---|---|---|---|
| China (Mainland) | 1.19 | 0.5 | 0.42 | 0.61 | 1.19 | Czech Republic | 3.29 | 1.48 | 1.67 | 1.04 | 0.88 |
| India | 1.13 | 0.47 | 0.48 | 0.87 | 1.06 | Bolivia | 1.71 | 0.65 | 0.83 | 1.2 | 0.81 |
| United States | 1.51 | 0.7 | 0.62 | 0.95 | 1.01 | Dominican Republic | 4.69 | 2.53 | 2.68 | 1.35 | 0.7 |
| Indonesia | 3.47 | 1.28 | 1.03 | 1.05 | 0.86 | Somalia | 1.3 | 0.64 | 0.83 | 1.16 | 0.64 |
| Brazil | 1.66 | 0.99 | 1.2 | 0.94 | 1.05 | Haiti | 2.04 | 0.83 | 0.84 | 1.05 | 0.9 |
| Pakistan | 1.69 | 0.88 | 0.96 | 1.26 | 0.77 | Benin | 1.03 | 0.54 | 0.5 | 0.57 | 1.41 |
| Nigeria | 3.35 | 1.48 | 1.5 | 1 | 0.89 | Hungary | 8.18 | 3.16 | 2.63 | 1.24 | 0.64 |
| Bangladesh | 2.71 | 1.85 | 2.16 | 1.14 | 0.76 | Burundi | 11.85 | 4.22 | 4.42 | 1.81 | 0.46 |
| Russian Federation | 2.36 | 1.49 | 1.48 | 0.95 | 1.03 | Sweden | 1.68 | 0.85 | 0.9 | 0.77 | 1.26 |
| Japan | 2.45 | 1.05 | 0.95 | 0.83 | 1.16 | Belarus | 3.75 | 1.54 | 1.41 | 1.2 | 0.82 |
| Mexico | 4.54 | 1.79 | 1.89 | 0.96 | 1 | Azerbaijan | 3.72 | 1.68 | – | 1.1 | 0.77 |
| Philippines | 1.67 | 0.64 | 0.61 | 0.8 | 1.12 | United Arab Emirates | 4.15 | 2.66 | – | 2.51 | 0.34 |
| Ethiopia | 10.83 | 3.7 | 2.93 | 1.09 | 0.79 | Austria | 6.54 | 2.89 | 3.23 | 1.32 | 0.62 |
| Vietnam | 2.54 | 1.52 | 1.78 | 1.19 | 0.8 | Tajikistan | 4.57 | 2.23 | 2.34 | 1.31 | 0.67 |
| Germany | 1.93 | 0.81 | 0.81 | 0.8 | 1.25 | Switzerland | 2.01 | 0.79 | 0.75 | 0.76 | 1.26 |
| Egypt, Arab Rep. | 1.87 | 0.93 | 1.35 | 1.13 | 0.86 | Honduras | 1.57 | 0.94 | 1.01 | 0.93 | 1.06 |
| Iran, Islamic Rep. | 2.97 | 1.33 | 1.22 | 1.01 | 0.98 | Israel | 1.97 | 0.88 | 0.73 | 0.82 | 1.19 |
| Turkey | 3.09 | 1.52 | 1.62 | 1.13 | 0.87 | Bulgaria | 3.58 | 1.39 | 1.51 | 1.08 | 0.9 |
| Thailand | 15.16 | 8.17 | 9.03 | 1.98 | 0.33 | Serbia | 5.03 | 2.06 | 2.15 | 1.09 | 0.81 |
| Congo, Dem. Rep. | 5.67 | 2.26 | 2.38 | 1.33 | 0.74 | Papua New Guinea | 2.36 | 1.56 | 2 | 1.43 | 0.65 |
| France | 6.71 | 2.54 | 2.34 | 1.13 | 0.87 | HK SAR, China | 2.12 | 1.1 | – | 1.22 | 0.66 |
| United Kingdom | 7.6 | 3.7 | 2.99 | 0.97 | 0.94 | Paraguay | 8.2 | 3.36 | 3.26 | 1.32 | 0.67 |
| Italy | 2.09 | 0.85 | 0.89 | 0.79 | 1.22 | Lao PDR | 6.53 | 2.68 | 3.09 | 1.66 | 0.57 |
| Myanmar | 5.87 | 3.54 | 4.24 | 1.37 | 0.57 | Togo | 8.81 | 3.16 | 2.93 | 1.41 | 0.59 |
| South Africa | 2.29 | 0.99 | 1.33 | 1.18 | 0.84 | Jordan | 2.68 | 1.22 | 1.35 | 1.2 | 0.83 |
| Korea, Rep. | 3.03 | 1.23 | 1.27 | 1.15 | 0.84 | El Salvador | 1.31 | 0.52 | 0.46 | 0.74 | 1.15 |
| Tanzania | 6.18 | 2.69 | 2.6 | 1.38 | 0.66 | Libya | 2.57 | 1.27 | 1.63 | 1.25 | 0.79 |
| Colombia | 3.22 | 1.31 | 1.54 | 1.14 | 0.87 | Eritrea | 4.43 | 2.08 | – | 1.72 | 0.55 |
| Spain | 1.18 | 0.68 | 1.01 | 0.84 | 1.18 | Nicaragua | 6.31 | 2.64 | 2.09 | 1.19 | 0.73 |
| Ukraine | 1.96 | 0.82 | 0.71 | 0.91 | 1.07 | Sierra Leone | 4.79 | 2.18 | – | 1.56 | 0.6 |
| Kenya | 2.61 | 1.63 | 2.05 | 1.26 | 0.73 | Denmark | 4.8 | 2.3 | 2.64 | 1.16 | 0.8 |
| Argentina | 9.35 | 3.75 | 3.53 | 1.31 | 0.72 | Kyrgyz Republic | 3.78 | 2.23 | – | 1.47 | 0.63 |
| Poland | 2.24 | 0.8 | 0.7 | 0.8 | 1.23 | Finland | 2.35 | 0.89 | 0.78 | 0.84 | 1.18 |
| Algeria | 2.94 | 1.48 | 1.41 | 0.88 | 1.1 | Slovak Republic | 1.71 | 0.99 | 0.96 | 0.85 | 1.11 |
| Sudan | 1.31 | 0.63 | 0.75 | 1.04 | 0.93 | Singapore | 1.04 | – | – | – | – |
| Uganda | 9.23 | 3.75 | 3.24 | 1.16 | 0.61 | Turkmenistan | 4.08 | 1.66 | 1.85 | 1.34 | 0.73 |
| Canada | 1.51 | 0.77 | 0.9 | 1.05 | 0.94 | Norway | 3.75 | 1.52 | 1.87 | 0.9 | 1.06 |
| Iraq | 4.17 | 1.66 | 1.51 | 1.39 | 0.67 | Costa Rica | 4.24 | 1.92 | 2.44 | 1.41 | 0.68 |
| Morocco | 4.55 | 1.32 | 1.11 | 1.17 | 0.84 | Ireland | 5.59 | 3.03 | 3.6 | 1.42 | 0.52 |
| Peru | 10.8 | 4.25 | 3.98 | 1.38 | 0.68 | Central African Republic | 2.74 | 1.72 | 2.14 | 1.42 | 0.64 |
| Venezuela, RB | 1.02 | 0.46 | 0.54 | 0.75 | 1.22 | Georgia | 5.96 | 2.63 | 3.03 | 1.53 | 0.61 |
| Afghanistan | 7.54 | 2.74 | 3.39 | 1.59 | 0.6 | New Zealand | 3.26 | 1.16 | 1.15 | 1.01 | 0.87 |
| Uzbekistan | 3.26 | 1.53 | 1.51 | 1.11 | 0.89 | Lebanon | 3.89 | 1.68 | 2.12 | 0.84 | 1.11 |
| Malaysia | 2.76 | 1.21 | 1.14 | 1.2 | 0.77 | Congo, Rep. | 1.92 | 1.58 | 2.63 | 2.04 | 0.46 |
| Saudi Arabia | 1.51 | 0.86 | 1.04 | 1.21 | 0.82 | Croatia | 4.12 | 1.81 | 1.87 | 1.21 | 0.78 |
| Nepal | 3.79 | 1.44 | – | 0.95 | 1.01 | Liberia | 17.93 | 6.84 | 6.44 | 1.92 | 0.52 |
| Ghana | 1.02 | 0.76 | 1.07 | 1.16 | 0.82 | Bosnia and Herzegovina | 2.45 | 1.21 | 1.26 | 1.11 | 0.88 |
| Mozambique | 1.37 | 0.63 | 0.69 | 0.98 | 0.91 | Panama | 1.37 | 0.77 | 0.77 | 0.96 | 0.99 |
| Korea, Dem. Rep. | 3.67 | 1.56 | 1.41 | 0.89 | 1.06 | Mauritania | 7.72 | 3.52 | – | 1.42 | 0.45 |
| Yemen, Rep. | 2.85 | 1.22 | 1.61 | 1.44 | 0.68 | Moldova | 4.65 | 1.82 | 2.18 | 1.24 | 0.71 |
| Chinese Taibei | 1.41 | 0.48 | 0.65 | 1.2 | 0.72 | Uruguay | 12.54 | 4.73 | 3.93 | 1.34 | 0.57 |
| Australia | 1.05 | 0.54 | 0.74 | 1.27 | 0.76 | Oman | 2 | 0.62 | 0.68 | 0.91 | 0.99 |
| Syrian Arab Republic | 1.51 | 0.87 | 1.11 | 1.06 | 0.92 | Kuwait | 1.15 | 0.55 | 0.59 | 1.05 | 0.71 |
| Madagascar | 8.18 | 3.06 | 3.04 | 1.21 | 0.57 | Albania | 3.7 | 1.48 | 1.29 | 1.11 | 0.86 |
| Cameroon | 1 | 0.67 | 1 | 1.21 | 0.8 | Lithuania | 1.66 | 0.89 | – | 1.19 | 0.82 |
| Romania | 5.8 | 2.02 | 1.46 | 0.99 | 0.98 | Armenia | 8.91 | 4.26 | 4.52 | 1.5 | 0.49 |
| Angola | 14.15 | 5 | 5.17 | 1.88 | 0.47 | Mongolia | 13.73 | 5.82 | 5.89 | 1.64 | 0.61 |
| Sri Lanka | 4.43 | 1.67 | – | 0.99 | 0.9 | Jamaica | 3.21 | 1.33 | 1.8 | 1.51 | 0.65 |
| Cote d'Ivoire | 10.78 | 6.18 | 6.3 | 1.51 | 0.45 | Namibia | 5.14 | 1.91 | 1.82 | 1.16 | 0.73 |
| Chile | 8.12 | 4.49 | 4.05 | 1.25 | 0.72 | Macedonia, FYR | 6.72 | 2.32 | 1.97 | 1.24 | 0.68 |
| Niger | 4.75 | 2.15 | 2.29 | 1.55 | 0.62 | Slovenia | 2.9 | 1.62 | 1.82 | 1.26 | 0.73 |
| Kazakhstan | 2.23 | 0.81 | 0.74 | 0.94 | 1 | Lesotho | 2.9 | 1.27 | 1.35 | 1.22 | 0.78 |
| Netherlands | 1.29 | 0.54 | 0.6 | 0.79 | 1.24 | Qatar | 1.33 | 0.67 | 0.93 | 1.27 | 0.7 |
| Burkina Faso | 3.21 | 2.39 | – | 1.64 | 0.53 | Latvia | 7.06 | 2.87 | 2.96 | 1.58 | 0.55 |
| Malawi | 1.02 | 0.76 | – | 1.52 | 0.6 | Gambia, The | 1.98 | 1.5 | – | 1.96 | 0.5 |
| Ecuador | 1.42 | 1.03 | 1.27 | 1.16 | 0.84 | Guinea-Bissau | 10.55 | 4.7 | 5.8 | 2.03 | 0.43 |
| Guatemala | 1.88 | 0.8 | 0.82 | 0.76 | 1.28 | Gabon | 5.09 | 2.13 | – | 1.61 | 0.6 |
| Cambodia | 7.37 | 3.12 | 3.07 | 1.41 | 0.59 | Estonia | 4.06 | 2.01 | 2.44 | 1.47 | 0.66 |
| Mali | 7.99 | 3.61 | 3.17 | 1.35 | 0.67 | Mauritius | 1.3 | 0.48 | – | 1.29 | 0.49 |
| Zambia | 3.48 | 1.51 | 1.69 | 1.27 | 0.77 | Swaziland | 1.45 | 1.15 | 1.54 | 1.33 | 0.7 |
| Senegal | 3.86 | 2.18 | 2.3 | 1.49 | 0.62 | East Timor | 9.24 | 3.82 | 3.54 | 1.54 | 0.49 |
| Zimbabwe | 2.27 | 1.24 | 1.54 | 1.29 | 0.77 | Cyprus | 1.49 | 0.55 | 0.48 | 0.65 | 1.45 |
| Chad | 6.93 | 2.86 | 2.86 | 1.22 | 0.67 | Fiji | 3.32 | 1.22 | 1.46 | 1.34 | 0.69 |
| Rwanda | 6.78 | 3.64 | 3.93 | 1.48 | 0.54 | Djibouti | 15.63 | 6.54 | 9.42 | 2.31 | 0.34 |

**Table 3** (*continued*)

| Name | Primacy ratio | 4-city ratio | 11-city ratio | Zipf | Hausdorff | Name | Primacy ratio | 4-city ratio | 11-city ratio | Zipf | Hausdorff |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Guinea | 8.59 | 3.19 | 2.86 | 1.41 | 0.51 | Montenegro | 2.65 | 1.68 | 1.76 | 1.26 | 0.7 |
| Greece | 3.93 | 2.73 | 3.43 | 1.36 | 0.61 | Macao SAR, China | 5.81 | – | – | 3.71 | 0.25 |
| Cuba | 5.01 | 2.12 | 2 | 1.19 | 0.81 | Suriname | 15.03 | 4.64 | 4.1 | 1.55 | 0.48 |
| Belgium | 1.94 | 0.92 | 1.08 | 0.66 | 1.5 | Luxembourg | 3.16 | 1.34 | 1.26 | 0.96 | 0.96 |
| Tunisia | 2.75 | 1.31 | 1.16 | 0.8 | 1.16 | Cape Verde | 1.81 | 1.28 | 1.72 | 1.46 | 0.65 |
| Portugal | 2.31 | 0.91 | 0.86 | 0.85 | 1.16 | Iceland | 3.73 | 1.55 | 1.79 | 1.41 | 0.7 |

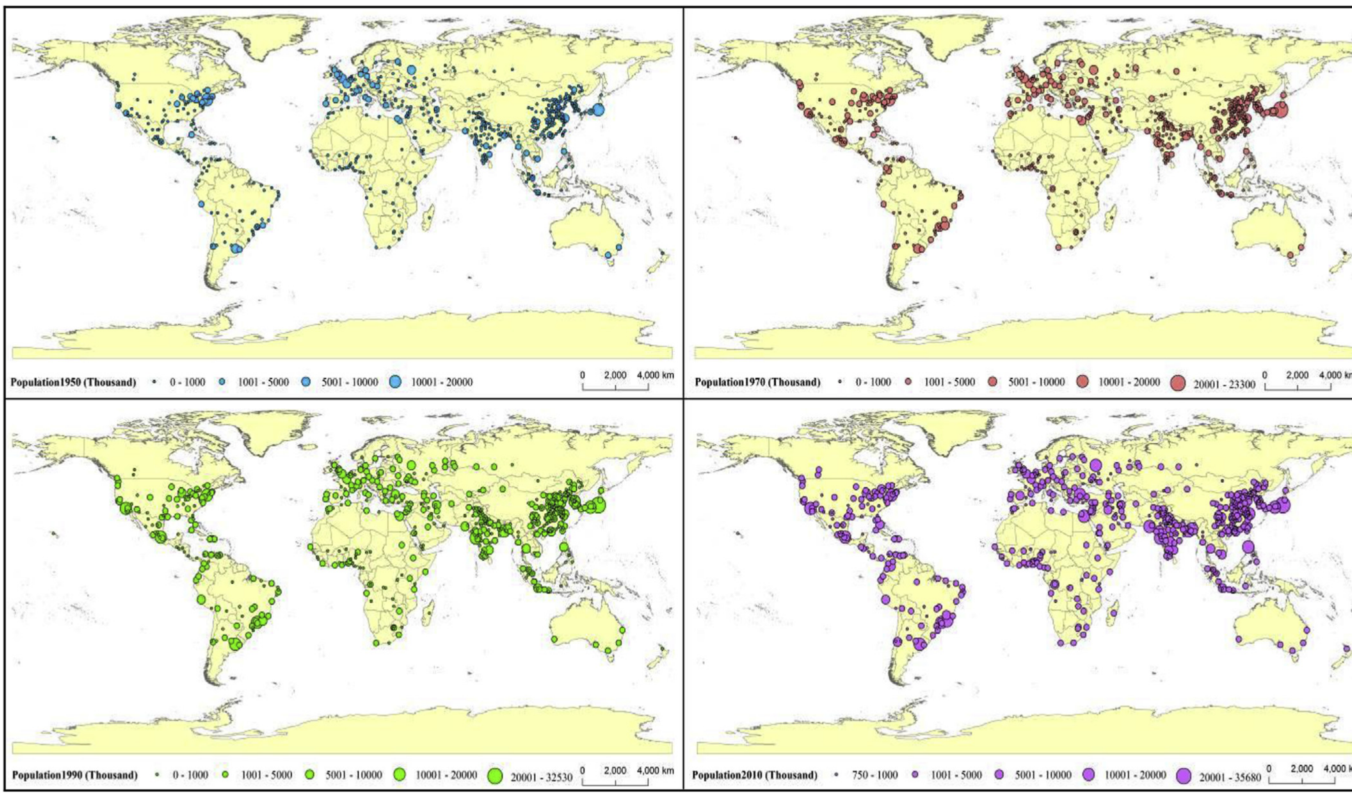


**Fig. 7.** Spatial-temporal differentiation of global urban agglomerations with populations above 750,000.

primacy ratio should be 2 and both the ideal four-city ratio and eleven-city ratio should be 1. But after calculating and analyzing relevant ratios in the world, the different economic development regions, all the continents, each country, region, and large urban agglomerations, the global primacy ratio is calculated at 1.06, while the global four-city ratio and eleven-city ratio are 0.37 and 0.26 respectively. These values indicate dissatisfaction with the development of the primate city, which means primate cities are not prominently featured in global city size distribution.

As for the different economic development regions, the primacy ratio and the four-city ratio of developed countries are the highest (1.51 and 0.55, respectively), the highest eleven-city ratio appears in the least developed countries (0.46), while the lowest of the three primate ratios appears in the developing countries (1.06, 0.37, and 0.27, respectively), revealing that the primate feature of city size distribution is relatively obvious in developed countries.

With respect to continents, North America has the highest primacy ratio and four-city ratio (1.51 and 0.70, respectively), Oceania has the highest eleven-city ratio (0.72) and the lowest primacy ratio (1.05), and Asia shows the lowest four-city ratio and eleven-city ratio (0.38 and 0.29, respectively), illustrating a relatively significant primate feature of city size distribution in North America. The countries and regions with ratio values closest to the ideal are Switzerland, with a primacy ratio 2.01, Slovakia and Japan, with four-city ratios of 0.99 and 1.05, respectively, and Spain and Slovakia, with eleven-city ratios of 1.01 and 0.96, respectively. Based on these values, the primate feature of global city size distribution is not very obvious. Moreover, significant differences exist among continents, economic development regions as well as countries and regions. Specifically, the primate features of city size distribution in North America, Europe, and the developed countries are relatively more significant, meaning that city size and agglomeration of large cities impart a more obvious effect; while, the primate distributions of Asia, Oceania, and the least developed countries are not close to their ideal situations, suggesting that city size and agglomeration of large cities have a relatively weak effect.

### *5.3. The rank-size distribution around the globe*

By calculating and analyzing Zipf exponents and Hausdorff dimensions in the world, the different economic development regions, all the continents, each country, region, and large urban agglomerations, the global Zipf exponent is calculated to be 0.66—less than both the theoretical value of a balanced population

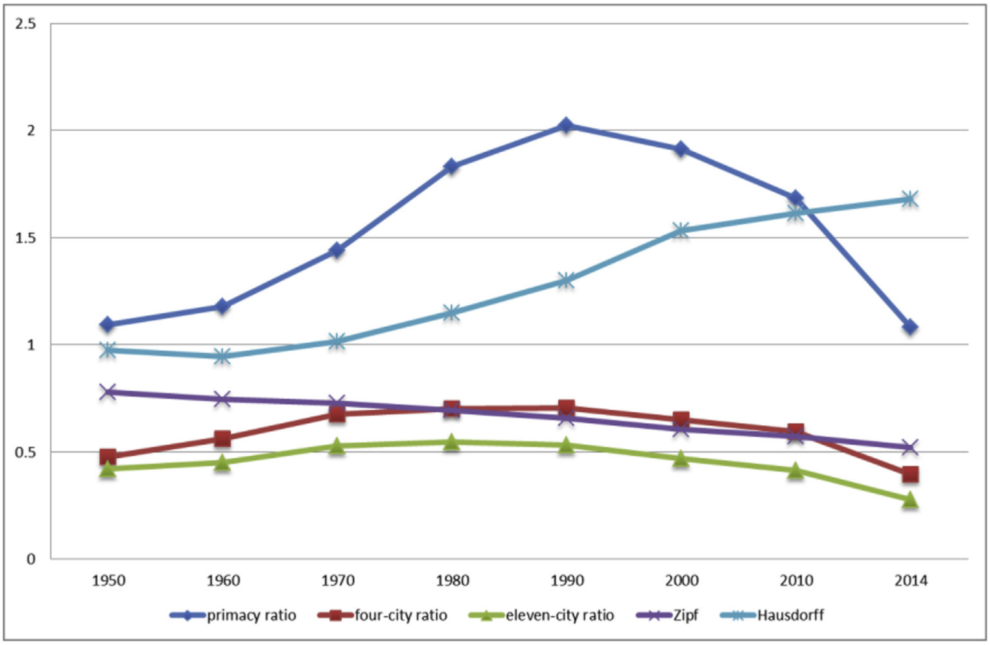


**Fig. 8.** Changes of city size distribution index of global urban agglomerations.

distribution 1 and the empirical value of the success of Zipf's law (0.8); while the Hausdorff dimension is 1.29—greater than the theoretical value of a balanced urban population distribution 1. This essentially means that, on a global scale, although the world urban population is not distributed evenly among cities of different sizes and major disparities in the level of urbanization do exist, medium and small cities are certain to be home to a large portion of the urban population. This suggests that in the global urban hierarchy system, cities with middle ranks are in the majority and the monopoly power of large and super cities is effective only to a certain extent.

As for the different economic development types, the least developed countries have the highest Zipf exponents (0.83) and the developing countries present the lowest ones (0.69). At the same time, the highest Hausdorff dimension appears in the developed countries (1.26) and the lowest value shows up in the least developed countries (1.15). Out of all the continents, Oceania has the highest Zipf exponent (1.10) and Asia has the lowest (0.71), meanwhile Europe presents the highest Hausdorff dimension (1.32) and Oceania, the lowest (0.86). With respect to each country and region, about 70% have a Zipf exponent greater than 1, and approximately 40% can be regarded as a successful example of Zipf's law because their empirical values fall within [0.8, 1.2]. Among those countries that nearly satisfy the standard and ideal of Zipf's law are New Zealand (1.01), Romania (0.99) and the United Kingdom (0.97). With respect to the Hausdorff dimension, more than 75% of countries and regions have a Hausdorff dimension less than 1, and the representative countries with Hausdorff dimensions equal to 1 include Mexico (1.0), the United States (1.01), Romania (0.98), and Luxembourg (0.96). Therefore, it can be inferred that only in Oceania is the differentiation of urban population distribution relatively high such that large cities exert a more powerful influence in Oceania, while in other continents, those urban hierarchy systems are developing with stability. This is particularly true in Europe and the developed countries where the distributions of urban populations are closest to the ideal state and their medium and small cities are prosperous with limited agglomeration effect of large cities. As a result, even though the distribution of urban population by city size class varies among major areas, it can be inferred that at the global level, city size is becoming more equally distributed, which means there is a decreasing concentration tendency in the city size distribution and cities of different sizes tend to converge in terms of relative population size, especially the medium and small cities.

### *5.4. Global urban agglomerations and growing cities in China*

By calculating results of primate city ratios, it was determined that the primacy ratio of global large urban agglomerations (urban regions with more than 750,000 inhabitants) fluctuates around 1.5 and approximated the theoretical ideal value 2 in 1990 (2.02). However, the four-city ratio and the eleven-city ratio altered to 0.6 and 0.45, respectively, each of which is significantly lower than the theoretical ideal value 1. As to the rank-size rule exponents, the Zipf exponent of global large urban agglomerations was always less than 1 and declined gradually to approximate 0.5 at present; and the Hausdorff dimension of global large urban agglomerations increased gradually along an elongate S-curve, exceeded 1 beginning in the 1970s and has remained above 1.5 starting in 2000. Consequently, although urban agglomerations have attracted considerable attention because of their population size and geographical complexity, they represent the extremes of urban population distribution. Overall, nearly half of the world's urban dwellers (50.9%) have been residing in relatively small urban settlements with fewer than 500,000 inhabitants, and the number of medium and small urban agglomerations increased rapidly, indicating a gradual shift to a more reasonable size distribution that balances global urban agglomerations systems.

Based on the statistics, it is also revealed that among the 525 global urban agglomerations with more than 1 million inhabitants, 100 of them are in China, accounting for 19.05% of all the agglomerations. Furthermore, among the 612 global large urban agglomerations (more than 750,000 inhabitants), 22.22% (a total of 136) are Chinese urban agglomerations. In addition, Chinese urban agglomerations and cities account for at least 10% of all kinds of urban agglomerations and cities of different sizes around the world.

**Table 4**
The number of cities with over 100,000 people in China by 2030.

| Country | The average population scale of the cities with over 100 thousand people (thousand) | The number of China's cities according to this country' standard | The increasing number of China's cities |
|---|---|---|---|
| Russia | 639.8 | 1407 | 750 |
| USA | 888.3 | 1013 | 356 |
| Canada | 687.1 | 1310 | 653 |
| Brazil | 674.4 | 1335 | 678 |
| Australia | 1192.1 | 755 | 98 |
| India | 836.6 | 1076 | 419 |
| South Africa | 998.6 | 901 | 244 |
| France | 960.5 | 937 | 280 |
| Japan | 446.6 | 2015 | 1358 |
| Germany | 798.1 | 1128 | 471 |
| Italy | 908.2 | 991 | 334 |
| UK | 630.4 | 1428 | 771 |
| Israel | 519.3 | 1733 | 1076 |
| Average of 181 countries | 693.6 | 1298 | 641 |
| Global average | 738.8 | 1218 | 561 |

Moreover, China accounts for more than 20% of all the megacities and megalopolitan cities around the globe. Among the megacities with more than 10 million inhabitants, 21.43% are in China; among the megalopolitan cities with more than 5 million inhabitants, 20.59% are in China; among the big cities with more than 1 million inhabitants, 17.86% are in China; among the cities with more than 500,000 inhabitants, 22.37% are in China; among the cities with more than 100,000 inhabitants, 26.10% are in China; among the cities with more than 50,000 inhabitants, 19.17% are in China; and among the cities with more than 20,000 inhabitants, 10.68% are in China. Therefore, it is predictable that in the future, the development of Chinese cities and urban agglomerations will significantly influence global urban progress and its spatial pattern.

### *5.5. Global experiences and implications for China*

The principle of the global city size hierarchy, summarized above, has an important reference value for developing countries. Given that China is the largest developing country, which has been experiencing rapid urbanization since 2000, and is now the world's second largest economy, the government and people of China should actively seek to understand these global experiences and their implications. In 2012, the average population of the cities with more than 100,000 people worldwide was 691,900; however, China's was only 499,500. According to China's current rate of urbanization, by 2030, the level of urbanization in China will be over 60%, and the urban population will be 0.9 billion (Fang & Yu, 2016). The growth center of China's urban population will move westward, and the urban and rural integration process will proceed significantly faster in the future (Mohabir, Jiang, & Ma, 2017). If we apply global experiences, the urbanization process of major developed countries, and the global averages to China's current situation, by 2030, the number of China's cities will reach 1218, which is 561 more than now (Table 4).

Therefore, given that China's population is moving toward 60–70% urbanization, the number of China's cities should increase reasonably, instead of adding the increasing urban population to existing cities. According to international experience, when urban populations exceed 2 million, generally the utilization efficiency of urban infrastructure and public service facilities reach maximum capacity. That is to say, 2 million people may the maximum number of people that should reside in a city in order to maintain health and order. Thus, with a total population of 1.5 billion people in China by 2030, we can estimate that 780–800 cities should be established between now and then for healthy and orderly urbanization and city development in China. In this urban system, the number of direct-controlled municipalities could remain at four, the number of prefecture-level cities could increase from the current 286 to at least 311, and the number of county-level cities could increase from the current 370 to at least 455 by rebuilding or transforming. For these purposes, China's government should take orderly actions such as adjusting administrative divisions by selecting the timing and mode of development; adapting measures to local conditions; coordinating different scale cities' development within urban agglomeration; and promoting farmer settlement in small and medium cities.

## Acknowledgement

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