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Spatiotemporal Variation and Inequality in China's Economic Resilience across Cities and Urban Agglomerations

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Abstract: Economic resilience is a critical indicator of the sustainable development of an urban economy. This paper measures the urban economic resilience (UER) of 286 major cities in China from six indicators—economic growth, opening up, social development, environmental protection, natural conditions, and technological innovation—using a subjective and objective weighting method and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods. Furthermore, kernel density estimation (KDE) was used to reveal the spatial and temporal trends in UER across cities, and a social opportunity function was applied to access the opportunity for economic resilience and the fairness of opportunities for economic resilience in 19 urban agglomerations in China. The results show that the UER was, in general, low across all cities but increased over time. Geographically, the UER disperses from the eastern coast to inland cities. Amongst urban agglomerations in China, the economic resilience opportunity index also varies spatially and increases over time. On the other hand, the opportunity fairness index of UER remained largely stable and substantial inequalities exist across all urban agglomerations, indicating the need for differentiated policy intervention to ensure equality and the sustainable development of the region. The methodology developed in this research can also be applied in other cities and regions to test its re-applicability and to understand the UER in different contexts.

Keywords: urban economic resilience; economic resilience opportunity; inequality; urban agglomeration

1. Introduction

The term "resilience" originates from engineering physics. The ecologist Holling (1973) used this term to describe the ability of a system to maintain stability or return to an original state after suffering an external perturbation [1]. Economists have also used the concept of resilience to explain complex interactions in global markets, and used economic resilience to define the ability of an economy to respond to risks. Such resilience is the result of evolutionary interactions among the economy, the external environment, effective governance, and other determinants [2].

Due to the accelerating process of economic globalization, world economies are increasingly interconnected and influenced by many external factors. The increasing awareness of such factors as environmental crises has strengthened people's understanding of economic vulnerability, thus stimulating new paths for urban development [3]. After perturbation by an external factor, some regions can quickly regain new stability and re-establish economic growth. Conversely, the economy can also respond sluggishly and be unable to recover in other areas [4]. In order to explore the driving factors behind the heterogeneous responses across regions, the concept of urban economic resilience (UER) was introduced [5]. This concept helps to explain the regional differences in resilience after economic shocks. Urban policy-makers have shown strong interest in applying UER to promote sustainable economic development, with resilience highlighted as critical to Britain's budget in 2014 [6]. Thus, urban economic resilience has become a research hotspot in urban economics, regional economics, development economics, economic geography, and other disciplines [7].

Internationally, research on urban economic resilience can be divided into two stages [8]: Stage 1 (2002–2010), where studies on UER were based on the equilibrium theory, including two kinds of cognitive approaches: engineering resilience and ecological resilience; and Stage 2 (2010–present), where research is formulated based on evolutionary resilience. The equilibrium theory emphasizes the ability of a region to recover from an economic crisis. It suggests that urban economic resilience is drawn from the stability of a region's structure and organization when facing a crisis [9]. The engineering resilience approach emphasizes the stability of the urban economy, focusing on the resilience of the socio-economic system after the impact. In this model, a region only has one equilibrium state [10]. Conversely, the ecological resilience approach claims that each region is a complex organization with multiple equilibrium states rather than a single equilibrium state [11]. This approach focuses on long-term economic development after a perturbation [12]. However, both approaches are of limited use in measuring UER, as they only consider the unemployment rate and the degree of GDP change before and after an economic crisis [13–15].

Recently, the approach to assess urban economic resilience has shifted from the equilibrium theory to the evolution theory [16], although the implications of this theory are yet to be fully understood. With this theoretical shift, the research focus is changing from understanding a region's ability to resist external threats to a focus on adapting to the complex external environments where those threats exist [17]. Thus, in the field of evolutionary economic geography, UER is defined as a continuous and constantly changing process. It is an intrinsic property of the region and evolves dynamically in response to changes in the external environment. The region acquires new knowledge from the outside world and continuously evolves and adapts to changes. This adaptive system characterizes the nature of urban economic sustainable development [18,19]. There are two main methods to evaluate UER under the evolution theory regime: the index system method [20] and the core variable method [21], but both methods have certain limitations.

First, the formation of the causal relationship between urban economic resilience and the urban economic system is unclear. The index selection method may not be representative of all urban economies, limiting the external validity of the results. Similarly, the core variable method only adopts the core variables of GDP and unemployment rate, which may not fully reflect the complex interactions in UER. Further research is also required to explore both methods in order to assess the trends in UER observations before and after a perturbation. Regional economic resilience can enhance the key attributes of the economic system in a long-term and sustainable way [22]. Furthermore, understanding resilience would require a new way of thinking about sustainability. By definition, resilience depends on being able to adapt to unprecedented and unexpected changes [23]. After an economic perturbation or crisis, sustainable development and economic resilience can reduce social welfare losses and reduce the negative effects of economic stimulus policies. Together, these can help to enhance urban economic resilience, if carefully managed.

There is little research on the economic resilience of cities in China [8,22]. China's economic growth is in the process of structural transformation. Factors such as labor supply, resource and environmental costs, advancements in technology, and external market demands are changing rapidly. Due in part to these changes, some industries are facing the challenge of exceeding their full capacity, which may impact on UER. In light of this, this paper aims at addressing three research questions: (1) How can we measure UER holistically in the context of Chinese cities? (2) Is the spatial distribution of UER heterogeneous or does it vary across all cities in China? (3) Does each city in an urban agglomeration have equal access to social opportunities? To address these questions, we first constructed a comprehensive evaluation framework based on evolutionary theory to measure urban economic resilience from six dimensions: economic development, opening up, environmental protection, social development, natural conditions, and technological innovation. We used a subjective and objective weighting method to weight each of these factors and applied this framework to evaluate the UER of 286 cities in China from 2004 to 2016. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to rank the UER across the 286 cities. The Kernel Density Estimation (KED) method was used to explain the evolution of economic resilience in the 286 cities from 2004 to 2016. Furthermore, the equality of opportunities for economic resilience in China's 19 agglomerations was assessed using the social opportunity and opportunity equality indexes to reveal the spatiotemporal variation in China's economic resilience across cities and urban agglomerations.

The rest of the paper is organized as follows. The next section introduces the materials and methods we use. Then, the third section presents results that illustrate the spatiotemporal evolution of the UER across 286 cities and 19 urban agglomerations, followed by discussion and conclusion in the last section.

2. Materials and Methods

2.1. Construction of the Indicator System

According to evolutionary economic geography, UER can be considered as an intrinsic feature of a region [22]. It is a historical path dependence that is continuously self-reinforcing due to urban historical heritage and external environmental influences [24]. This historical path depends on the industrial structure, the organization of production, social politics, the ecological culture, and the climate of innovation formed by long-term evolution [25]. From the evolutionary perspective, if a region can identify adaptive locks to its destructive changes, this region can enhance its adaptability and improve the region's economic resilience [26]. For example, Martin and Sunley (2007) [18] identified effectively several "unlocking" mechanisms that can improve urban resilience, including (1) innovations generated by the use of heterogeneous economic entities; (2) introduction and integration of external resources; (3) diversified industrial development; and (4) economic structural transformation and upgrading. The improvement of UER is a continuous process, in part through these mechanisms. Briguglio et al. (2006) quantified the economic resilience of 86 countries through a series of indicators, such as macroeconomic stability, micro-market efficiency, good economic governance, and social development [27]. On a different scale, Guillaumont (2009) constructed the national scale, spatial location, specialization, natural shock, and trade impact as indicators of the economic vulnerability of a region [28]. In general, the less economic vulnerability a region has, the stronger the region's economic resilience is.

We constructed an indicator system consisting of 25 indicators to assess UER across all China from 2004 to 2016, except for 12 prefecture-level cities. These indicators were selected according to three broad criteria—data availability, comparability with indicators drawn from the literature, and regional variation—to measure UER from six dimensions: economic growth, opening up, social development, environmental protection, natural conditions, and technological innovation. Data used to operationalize the indicator system were sourced from either the China Urban Statistical Yearbook (2005–2017) or the statistical yearbook for the province in which the city is located. The 12 cities excluded from this analysis include Sansha and Zhanzhou in Hainan Province; Bijie and Tongren in Guizhou Province; Rikeze, Changdu, Linzhi, Shannan, and Naqu in Tibet Autonomous Region;

Haidong in Qinghai Province; and Hami and Tulufan in Xinjiang Uygur Autonomous Region, where no data is available for the duration of our study period.

(1) Economic growth is characterized by macroeconomic stability and micro-market efficiency [27]. Fiscal expenditures can reflect the government's policies on investment, construction, and development of urban infrastructure and welfare. Strong financial growth helps policy-makers to formulate flexible economic policies and more effectively resist the negative impact of a crisis or perturbation on the economy. The proportions of industry and the number of employees in tertiary industry can be used to estimate industrial diversification. A more diversified industrial structure can act as a "shock absorber" to eliminate the negative impact of economic shifts in the region. In turn, this can help to improve the overall adaptability of the urban economy [29]. Furthermore, urban land under construction can act as a proxy for the speed of urban construction and development; and indicators such as employment, per capita GDP, and fixed asset investment can be used to measure the stability of economic development in a region and, thus, UER.

(2) To measure the extent of opening up, we chose the number of foreign investment projects in the region [30]. The international economic crisis is one of the factors contributing to the economic recession of the city. The opening up of the larger economic market and the technical level of export goods and services can in part reflect the economic fragility within the international community and may limit external economic crises to the internal region.

(3) In terms of social development, the number of Internet-connected devices, such as mobile phones, can indicate the saturation of social development and the efficiency of social progress. Additionally, as society grows more socially advanced, the quality of education will also increase. Education expenditure and the number of colleges and universities can be used as indicators of the quality of education. In particular, highly skilled people trained with higher education can be transformed into valuable human resources and become an endogenous driving force of urban development.

(4) For environmental protection, green development is a pathway for economic growth and social development that focuses on efficiency and sustainability [30]. Green indicators are associated with sustainable economic development. To a certain extent, the green industry can promote the adjustment of economic structure, breaking through constraints, managing the risks brought about from the environment, and promoting the sustainable development of the economy.

(5) Indicators measuring natural conditions include both the population and the size of the administrative area, as they can measure the city's natural resistance and potentially reduce the vulnerability of a city's economy [28]. A flexible multi-skilled workforce can be used as a shock mitigation tool for the crisis. By transferring resources within a city, it is relatively easy to meet the shocks of negative external demand. Cities with larger administrative areas and larger populations have greater resistance to non-human crisis factors, such as natural disasters, thus reducing the interference of natural factors on urban economic development.

(6) For technological innovation, a measure of new technologies must be selected. However, the economic development in China has started to slow down. The rapid development of resource consumption is not sustainable due to this slowed development [31,32]. To measure this, we selected the total number of academic publications, innovative talents, the number of patents, and technology funds to measure the overall strength of technological innovation in each region. Strong scientific and technological innovation can assist in reducing excessive dependence on material production for economic development. Continuous innovation can enhance value chains and products to improve quality and efficiency, thus improving the region's ability to cope with and adapt to risks and challenges.

Table 1 lists all indicators and how they are operationalized using data from various sources. The weighting of each indicator was obtained by a subjective and objective comprehensive weighting method, which is introduced in the next section.

Table 1. China's urban economic resilience evaluation index system.

Total Target Level	Sub-Target Layer	Indicator Layer	AHP Weight	Entropy Weight	Comprehensive Weight
China's urban economic resilience evaluation index system	Economic growth index	X_1: Number of employees in the tertiary industry (10,000 people)	0.0291	0.0397	0.0870
		X_2: The third industry accounts for the proportion of GDP (%)	0.1070	0.0070	0.0441
		X_3: Total employment (10,000 people)	0.0514	0.0375	0.0920
		X_4: Urban construction land (square kilometers)	0.0069	0.0346	0.0002
		X_5: Fixed assets investment (ten thousand yuan)	0.0111	0.0209	0.0004
		X_6: GDP per capita (yuan)	0.1070	0.0126	0.0830
		X_7: Local public finance expenditure (ten thousand yuan)	0.0177	0.0276	0.1023
	Opening up index	X_8: Foreign direct investment contract projects (a)	0.0296	0.1066	0.0567
		X_9: The actual amount of foreign investment used in the year (US$10,000)	0.0591	0.0646	0.0579
	Social development index	X_{10}: Education expenditure (ten thousand yuan)	0.0071	0.0513	0.0956
		X_{11}: Number of colleges and universities(a)	0.0146	0.0565	0.0007
		X_{12}: Internet broadband access users (10,000 households)	0.0156	0.0310	0.0012
		X_{13}: Mobile phone year-end users (10,000 households)	0.0156	0.0245	0.0003
	Environmental protection index	X_{14}: General industrial solid waste comprehensive utilization rate (%)	0.1844	0.0038	0.0003
		X_{15}: Sewage treatment plant centralized treatment rate (%)	0.1064	0.0034	0.0011
		X_{16}: Harmless treatment rate of domestic garbage (%)	0.0555	0.0023	0.0010
		X_{17}: Green coverage rate in built-up areas (%)	0.0393	0.0036	0.0021
	Natural condition index	x_{18}: Household registration population at the end of the year (10,000 people)	0.0149	0.0122	0.0004
		X_{19}: Natural growth rate (%)	0.0088	0.0066	0.0008
		X_{20}: Administrative area land area (square kilometers)	0.0063	0.0259	0.0006
		X_{21}: Population density	0.0149	0.0151	0.0004
	Technological Innovation Index	X_{22}: Science and technology expenditure (ten thousand yuan)	0.0264	0.0795	0.1089
		X_{23}: Number of scientific research and technical service employees (10,000 people)	0.0401	0.2011	0.0876
		X_{24}: The total number of Chinese and English papers (Article)	0.0264	0.0370	0.0875
		X_{25}: Three major patent licenses (a)	0.0694	0.0591	0.0879

2.2. *Analytical Methods*

We used the subjective and objective weighting method to assign weight to each of the indicators we constructed to assess UER. Other methods, including the TOPSIS model, Kernel Density Estimation, and Social Opportunity Function, were used to rank the 286 cities' UER and explore the spatiotemporal variation and inequality in China's economic resilience across cities and urban agglomerations.

2.2.1. Subjective and Objective Weighting Method

In order to create a representative index, the subjective weighting method and the objective weighting method were used to jointly determine the weight of the indicators that satisfy the subjective and objective conditions [33].

2.2.2. The TOPSIS Model

We used TOPSIS as a multi-criteria decision analysis model to evaluate China's urban economic resilience using economic resilience indicators in 286 cities from 2004 to 2016. By measuring the closeness of the sample to be evaluated and an "optimal plan", the ranking of the evaluation samples is achieved [34–36]. A four-step approach was used to create the TOPSIS model.

Step 1: Construct a standardized matrix: $X = \{x_{ij}\}_{m \times n}$, to standardize all indicators:

$$\begin{cases} \frac{(x_{ij}-x_{min})}{(x_{max}-x_{min})} & xij \text{ (benefit index)} \\ \frac{(x_{max}-x_{ij})}{(x_{max}-x_{min})} & xij \text{ (cost index)} \end{cases} \quad (I = 1,\ 2,\ 3 \ldots\ m;\ j = 1,\ 2,\ 3 \ldots\ n) \tag{1}$$

where x_{ij} is the normalized value of the jth indicator of the ith city.

Step 2: Determine the "optimal plan" X^+ and "worst plan" X^-:

$$X^+ = \{x_1^+,\ x_2^+,\ x_3^+,,x_n^+\},\ X_j^+ = max_j\{x_{ij}\}(i = 1,\ 2,\ 3 \ldots\ m) \tag{2}$$

$$X^- = \{x_1^-, x_2^-, x_3^-,,x_n^-\},\ X_j^- = min_j\{x_{ij}\}(i = 1,\ 2,\ 3 \ldots\ m) \tag{3}$$

where x_i^+ is the optimal value of the indicator and x_i^- is the worst value of the indicator.

Step 3: Calculate the sum distance between the individual samples X^+ and X^-:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} w_j(x_{ij} - x_j^+)^2}(i = 1,\ 2,\ 3 \ldots\ m) \tag{4}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} w_j(x_{ij} - x_j^-)^2}(i = 1,\ 2,\ 3 \ldots\ m) \tag{5}$$

where D_i is the weight coefficient between the indicator data.

Step 4: Calculate the relative closeness of each sample to the "ideal" sample:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}(i = 1,\ 2,\ 3 \ldots\ m) \tag{6}$$

where, C_i is the closeness of the ith sample and the "optimal plan"; $0 \leq C_i \leq 1$.

2.2.3. Kernel Density Estimation

We used kernel density estimation to reveal the spatial and temporal trends in UER across 286 cities in China from 2004 to 2016. Kernel density estimation is a density function used to estimate unknown values based on the probability theory using a nonparametric test method [37–40]. This function was used in this study to produce a smooth surface of UER across the country based on values of the 286 cities. For a set of data $x_1, x_2, \ldots, x_n$, the kernel density estimate takes the form of:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k(\frac{x - x_i}{h}) \tag{7}$$

where, h is the window width, and the kernel function k is a weighting function. There are many methods for estimating nuclear density, including Gaussian kernel, Epanechnikov kernel, triangular kernel, and quadratic kernel. The selection of the kernel size is based on the intensity of grouped data. This study uses a Gaussian kernel function:

$$Gaussian : \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2}. \quad (8)$$

Silverman (1986) noted in the case of large samples that different kernel functions do not strongly impact on the estimator, but the selection of window width h can bias the estimator. The choice of window width determines the accuracy of kernel density estimation and the smoothness of the kernel density map [41]. The window width in this research is set to $h = 0.9SN^{-0.8}$, according to Silverman (1986), where N is the number of cities and S is the standard deviation of the values across all cities.

2.2.4. Social Opportunity Function

Drawing on the inclusive research of Ifzal Ali (2007) and Hyun Hwa Son (2010), we used the social opportunity function [42,43] to address our third research question on whether cities in urban agglomeration have equal access to social opportunities to gain economic resilience. We used the economic resilience of 286 cities in China to measure the equality of opportunity for economic resilience across 19 urban agglomerations in China [44].

The opportunity curve and the change in the opportunity distribution during the upward movement process are shown below (Figure 1) [45].

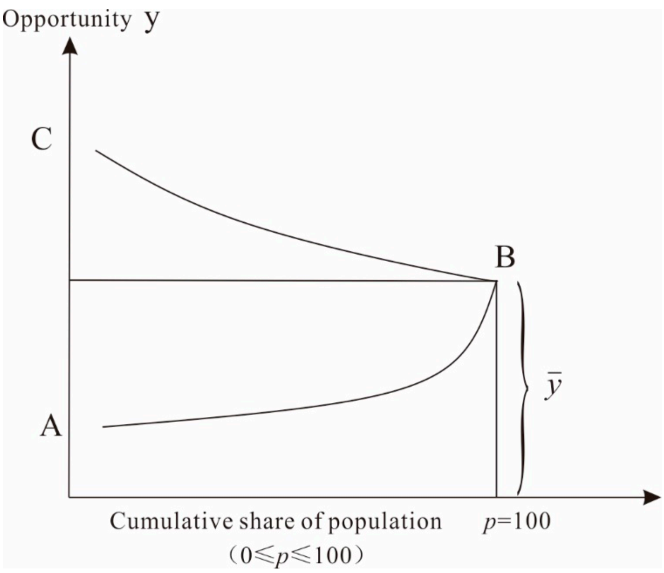

Figure 1. The opportunity curve.

3. Results

3.1. Spatiotemporal Evolution of UER across 286 Cities in China

3.1.1. Temporal Variations

The temporal change in UER across all 286 cities in China was measured from 2004 to 2016 using our comprehensive index system. The results were grouped into three categories based on their geographical regions—east, middle, and west—with the average UER in each region calculated and presented in Table 2. The results show that the average score of UER increased from 0.0562 in 2004 to 0.740 in 2016. The economic resilience of various regions increased each year; for example, in the eastern region, the score of UER increased from 0.0888 in 2004 to 0.1101 in 2006. Thus, there is a clear spatial variation in UER across different regions in China. The UER in the eastern region is much higher than that in the central or the western regions. We can infer that the gap between the economic resilience of the central and western regions has widened over time. During the study period, the economic resilience of the eastern region increased by 0.0213, and the central and western regions increased by 0.0175 and 0.0144, respectively. The UER in the eastern region increased faster than in the central and western regions. Similarly, the average UER in the eastern region is higher than the average of all cities, while the average of UER in the central and western regions is lower than the nationwide average. The developed economic foundation, strong material conditions, high level of opening up, and a good environment for scientific and technological progress in the eastern region have contributed to further improvement of UER in that region, and sustainable economic development. On the other hand, regions in the central and western part of the country lack the capacity for their large state-owned enterprises to transform and open up to the new markets, and their economic resilience is poor and not conducive to sustainable economic development. Although programmes such as the 'development of the western region' and the 'rise of the central region' have been launched and have improved the economic resilience of the central and western regions, there is still a large gap between these and the eastern region.

Table 2. Average score of urban economic resilience (UER) in cities across three geographical regions in China.

Region	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Eastern	0.0888	0.0889	0.1091	0.1093	0.1091	0.1089	0.1092	0.1094	0.1097	0.1097	0.1098	0.1098	0.1101
Central	0.0430	0.0425	0.0556	0.0561	0.0558	0.0556	0.0568	0.0572	0.0585	0.0586	0.0591	0.0594	0.0605
Western	0.0370	0.0368	0.0503	0.0503	0.0501	0.0495	0.0500	0.0503	0.0502	0.0504	0.0509	0.0511	0.0514
Average	0.0562	0.0560	0.0718	0.0719	0.0716	0.0713	0.0718	0.0723	0.0728	0.0729	0.0732	0.0732	0.0740

Results from the kernel density estimate are plotted against UER in 2004, 2010, and 2016 (Figure 2). This figure illustrates a one-peak distribution of UER in Chinese cities over all three time points, indicating that the difference in economic resilience across cities is large, with no substantial changes over time, and the economic resilience in most cities has a UER value between 0 and 0.1. Only a small number of cities have an economic resilience above 0.1. In contrast, the peak value of the kernel density in 2004 reached over 30. The proportion of cities with low economic resilience is far greater than those with high economic resilience, resulting in low overall economic resilience of Chinese cities. This peak UER value decreased rapidly to less than 25 in 2010, and, by 2016, the peak value was further reduced but at a much slower pace, with the number of lower UER cities reduced as well, indicating that the UER in Chinese cities grew faster in the 2004–2010 period than in the 2010–2016 period. On the other hand, the peak points of the three kernel density curves moved gradually toward the right side of the x-axis, indicating an increasing tendency toward economic resilience in Chinese cities.

Furthermore, the near identical shape of the UER distributions in 2010 and 2016 and their deviation from the 2004 chart with a higher tail after the value 0.1 indicate that cities with low economic resilience were gaining resilience at a faster speed, slowly reducing the gap in cities with high and low economic resilience in recent years (Figure 2).

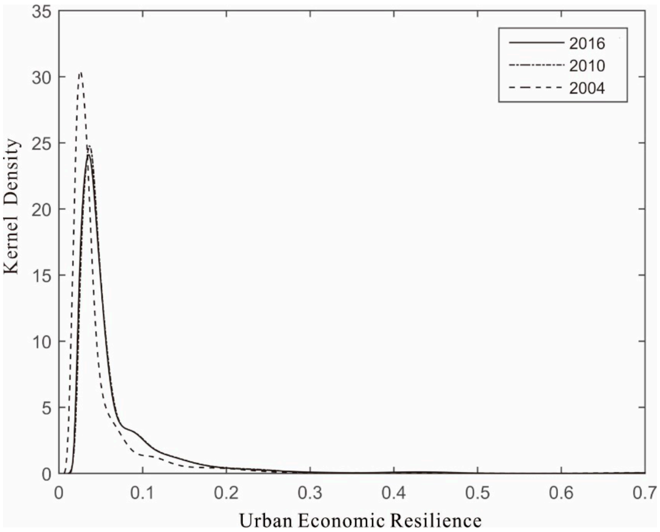

Figure 2. Estimation of China's urban economic resilience kernel density from 2004 to 2016.

3.1.2. Spatial Variations

According to the quartile measurement of economic resilience of 286 cities in China (Appendix A Table A1), the spatial distribution map of China's UER in 2004 and 2016 is drawn (Figure 3).

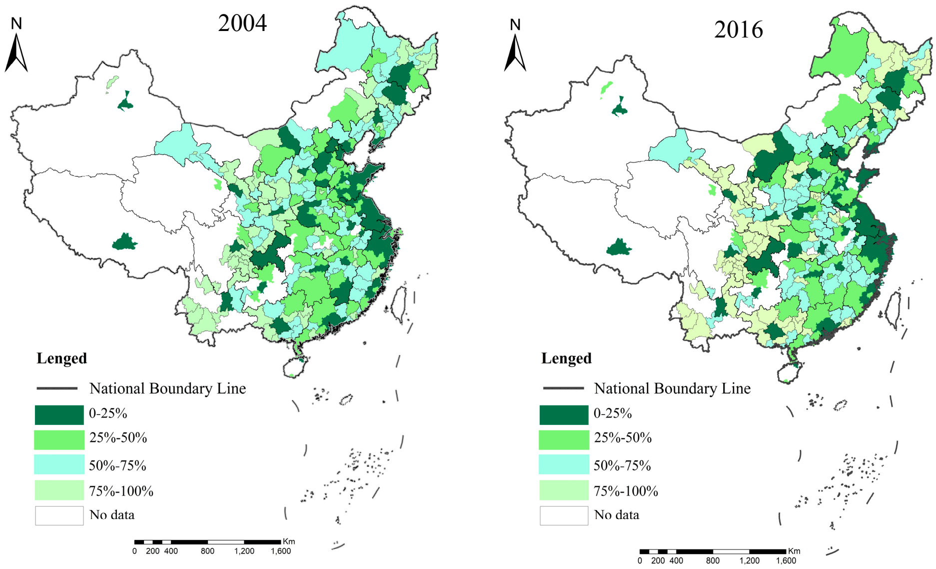

Figure 3. Spatial distribution of urban economic resilience ranking in china from 2004 to 2016.

Figure 3 shows that the UER scores of the 286 cities are not evenly distributed, with cities in the top 25% of economic resilience located on the eastern and northern coast of China. In 2016, Beijing, Shanghai, and Shenzhen ranked in the top three with 0.76, 0.69, and 0.44, respectively. Next, Suzhou, Chongqing, Tianjin, Guangzhou, Chengdu, Hangzhou, and Nanjing ranked 4th to 10th. Compared with 2004, the first two rankings did not change. Shenzhen made the fastest progress, rising by three places, moving from the sixth to the third, and Hangzhou rose from tenth to ninth. The top 10 cities in China's urban economic resilience are located in eastern China, except Chengdu and Chongqing.

In 2016, the top 25% of cities in China's UER are generally municipalities or provincial capitals. Other cities are generally located in the eastern coastal areas of China. These mainly include the core cities of Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, Chengdu-Chongqing, Central Henan, and the middle reaches of the Yangtze River. Among these cities, their economic resilience is much higher than cities around them. Compared with 2004, the top 25% of the economic resilience in 2016 is more spatially dispersed in eastern China. Looking to the central and western regions, the uneven distribution of economic resilience in various regions has improved to some extent from 2004 to 2016. In 2016, China's UER ranking included cities within the top 25–75% of selected cities, scattered throughout all provinces in China. Although compared with 2004 the scores have improved slightly, the pattern of the proportion of cities with lower UER scores has not changed. In 2016, compared with the 25% of cities in China's UER in 2004, these low-scoring cities were mainly located in western China. It shows that the western region's sustainable development capability is poor and its economic resilience is weak.

3.2. Economic Resilience and Opportunity Index across Urban Agglomerations

3.2.1. Spatial Distribution of Economic Resilience of Urban Agglomerations

The Chinese government has proposed that 19 urban agglomerations (Figure 4) will be built during the 13th Five-Year Plan period (2016–2020), namely: Beijing-Tianjin-Hebei, Central Shanxi, Hu-Bao-E-Yu, South Central Liaoning, Harbin-Changchun, Yangtze River Delta, West side of the Straits, Central Henan, Shandong Peninsula, Middle reaches of the Yangtze River, Pearl River Delta, Beibu Gulf, Chengdu-Chongqing, Central Guizhou, Central Yunnan, Guanzhong Plain, Lanzhou-Xining, Ningxia, and the North slope of Tianshan Mountain. Including the Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta are together positioned as a world-class city group. The 19 urban agglomerations include almost all provincial capital cities in the provincial-level regions, forming a regional economic development pattern centered on provincial capitals, economically developed cities, and regional central cities.

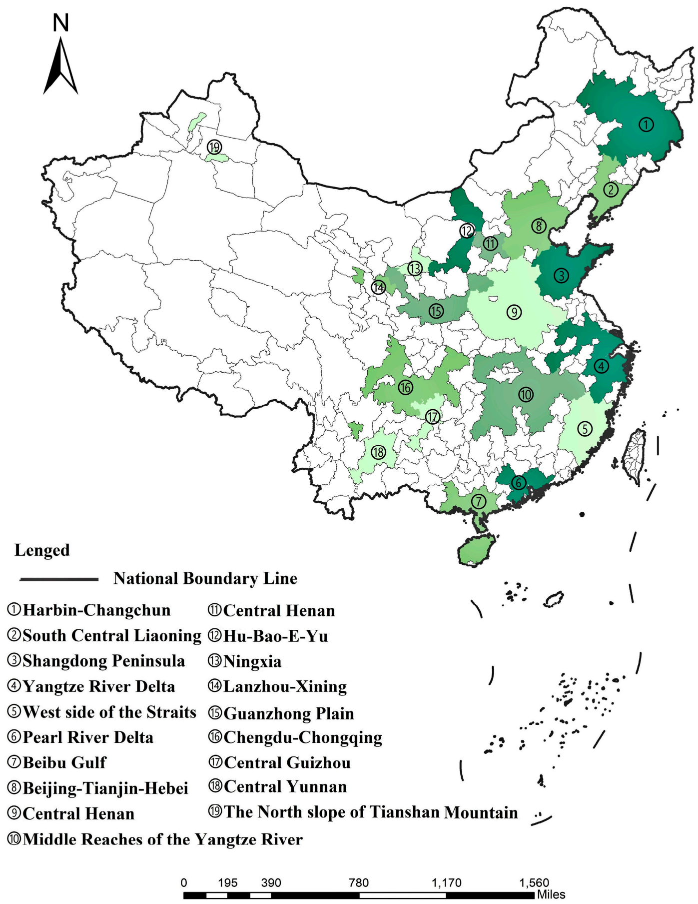

Figure 4. A schematic diagram of the spatial distribution of 19 Urban Agglomerations in China.

Summarizing the UER within the urban agglomerations as important centers of economic resilience, most of the economic resilience of the urban agglomerations in 2004 is concentrated below 0.05. In 2016, the economic resilience of most urban agglomerations is between 0.05 and 0.1 (Figure 5), and the economic resilience of each urban agglomeration has mostly increased. The three most economically resilient urban agglomerations in 2004 were the Beijing-Tianjin-Hebei, Pearl River Delta, and Yangtze River Delta urban agglomerations. These urban agglomerations are also the three most economically developed regions in China. The three urban agglomerations with the lowest economic resilience are the Lanzhou-Xining, the Beibu Gulf, and the Ningxia urban agglomerations, all located in the western region of China. In 2016, there were no major fundamental changes in the economic resilience pattern of China's urban agglomerations. Some of the observed changes were that the Pearl River Delta urban agglomeration had become China's most economically resilient urban agglomeration, and the Beijing-Tianjin-Hebei urban agglomeration ranked second, with the Yangtze River Delta urban agglomeration still ranked third. Although the relative position of economic resilience of other urban agglomerations had changed, the basic pattern of economic resilience of China's urban agglomerations did not change, and the trend from the eastern coastal areas to the western inland areas has been decreasing.

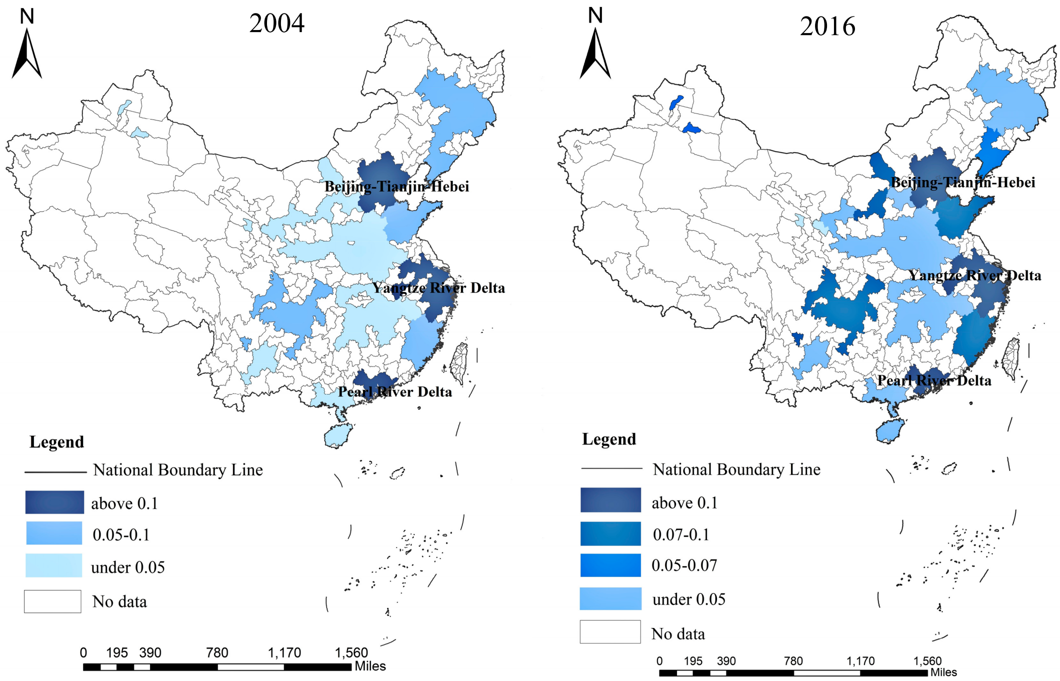

Figure 5. Spatial distribution of economic resilience of China's urban agglomerations scores from 2004 to 2016.

3.2.2. Opportunity Index and Opportunity Equity Index of China's Urban Agglomeration

Based on the previous calculations of the economic resilience of 286 cities in China from 2004 to 2016, the opportunity index was calculated (Table 3). From the perspective of time, with the rapid economic development in 2004–2016, the economic resilience opportunity index of each urban agglomeration has been increasing. The economic resilience opportunity curve increases with time, as social opportunity expands, as illustrated in curve AB (Figure 1). It shows that the economic resilience opportunities of urban agglomerations are not fair during the study period, and cities with higher economic resilience within urban agglomerations are more likely to obtain development space than cities with lower economic resilience. Among them, the economic resilience index of the Yangtze River Delta and the Pearl River Delta urban agglomeration increased at the greatest rate, both 37.03%, followed by the Ningxia urban agglomeration and the Lanzhou-Xining urban agglomeration, which increased by 31.62% and 31.57%, respectively. In 2004–2008, the economic resilience opportunity index of each urban agglomeration increased, and the UER opportunity index of most urban agglomerations increased significantly. Due to the impact of the economic crisis in the second half of 2008, the growth rate of the economic resilience index of most urban agglomerations slowed down markedly. The Beijing-Tianjin-Hebei, the central Shanxi, and the North slope of Tianshan Mountain urban agglomerations showed a small decline. In 2012–2016, the UER opportunity index stabilized, the Chengdu-Chongqing urban agglomeration's index increased by 0.0119, followed by the Yangtze River Delta urban agglomeration, which increased by 0.0094; the North slope of Tianshan Mountain urban agglomeration decreased by 0.0015, while the Lanzhou-Xining urban agglomeration declined at 0.0014, and the urban agglomeration in central and southern Liaoning fell by 0.0003.

Table 3. The economic resilience opportunity index and opportunity equity index of 19 urban agglomerations in China.

Urban Agglomeration	Opportunity Index				Opportunity Fairness Index			
	2004	2008	2012	2016	2004	2008	2012	2016
Beijing-Tianjin-Hebei	0.1051	0.1441	0.1398	0.1442	0.67	0.73	0.72	0.71
Central Shanxi	0.0253	0.0306	0.0304	0.0333	0.78	0.74	0.74	0.77
Hu-Bao-E-Yu	0.0343	0.0435	0.0448	0.0487	0.91	0.84	0.84	0.86
South-Central-Liaoning	0.0629	0.0807	0.0852	0.0849	1.09	1.04	1.08	1.01
Harbin-Changchun	0.0511	0.0605	0.0632	0.0670	0.94	0.90	0.91	0.91
Yangtze River Delta	0.1820	0.2110	0.2400	0.2494	0.96	1.01	1.15	1.16
West side of the Straits	0.0473	0.0675	0.0676	0.0754	1.02	1.04	1.09	1.14
Shandong Peninsula	0.0567	0.0700	0.0712	0.0735	0.95	0.91	0.91	0.89
Central Henan	0.0353	0.0410	0.0428	0.0480	0.92	0.88	0.88	0.90
Middle reaches of the Yangtze River	0.0379	0.0441	0.0462	0.0506	0.80	0.73	0.76	0.77
Pearl River Delta	0.0826	0.1062	0.1254	0.1327	0.66	0.67	0.76	0.76
Beibu Gulf	0.0352	0.0398	0.0414	0.0451	1.02	0.93	0.95	0.95
Chengdu-Chongqing	0.1579	0.1663	0.1738	0.1857	1.45	1.39	1.48	1.45
Central Guizhou	0.0222	0.0255	0.0270	0.0289	0.90	0.88	0.89	0.89
Central Yunnan	0.0257	0.0284	0.0303	0.0323	0.89	0.85	0.86	0.86
Guanzhong Plain	0.0401	0.0456	0.0545	0.0576	0.84	0.75	0.89	0.85
Lanzhou-Xining	0.0234	0.0302	0.0356	0.0342	0.78	0.80	0.95	0.82
Ningxia	0.0199	0.0235	0.0249	0.0291	0.97	0.82	0.82	0.83
North slope of Tianshan Mountain.	0.0095	0.0138	0.0121	0.0106	1.06	1.02	1.02	1.01

From the perspective of space, the UER opportunity index of various urban agglomerations in China shows spatial non-equilibrium. According to the average of the 2004–2016 UER opportunity index, the 19 urban agglomerations were divided into three categories using Jenks' natural breaks method. The first level is the Yangtze River Delta, Chengdu-Chongqing, Pearl River Delta, and Beijing-Tianjin-Hebei urban agglomeration. The economic resilience index of these four urban agglomerations (Yangtze River Delta, Chengdu-Chongqing, Pearl River Delta, Beijing-Tianjin-Hebei) is the highest. Except for the Chengdu-Chongqing urban agglomeration, the other three urban agglomerations are located on the eastern coast. The region is currently the largest urban agglomeration in China, with a total of 62 cities, and its average economic resilience index is above 0.1. These regions have developed economies, a relatively high degree of openness to the outside world, and close economic linkages between cities. These regions also have significant spillover effects, such as factor flows, technological innovation, and technology diffusion, which have led to a steady increase in the economic resilience of surrounding cities. The Chengdu-Chongqing urban agglomeration is positioned as the economic center of Southwest China, with Chongqing and Chengdu as the central cores, with a total of 17 cities. It is an urban agglomeration with a large regional role: it actively undertakes industrial transfer, and fosters and expands industrial clusters. In addition, the agglomeration has rapid economic development, strong urban service functions, and a wide hinterland. It has clear effects on the radiation belts in China's inland areas, a high economic resilience index, and a strong sustainable development capability. The second level is the Hu-Bao-E-Yu, Harbin-Changchun, South Central Liaoning, West side of the Straits, Central Henan, Middle Reaches of Yangtze River, Guanzhong Plain, Shandong Peninsula, and Beibu Gulf urban agglomeration. The average economic resilience index of urban agglomerations at this level is 0.03–0.1, including 124 cities, accounting for 59.6% of the 19 urban agglomerations. In addition, improving the economic resilience of second-tier urban agglomerations is key to improving China's overall economic resilience. Although the UER opportunity index of this type of urban agglomeration is at an intermediate level, it is different from the first-level area of the UER opportunity index. This second-tier UER still has great room for improvement, so the city's sustainable development capacity needs to be promoted. The third level is the Central Shanxi, Central Guizhou, Central Guizhou, Lanzhou-Xining, Ningxia, and North Slope of the Tianshan Mountain urban agglomeration. The average economic resilience opportunity index of this group is relatively lower, all below 0.03, a total of 22 cities. Except for the urban agglomerations in Central Shanxi, others are mainly located in western China. The industrial structure of these cities is relatively simple, it is easy to be locked in by the city, and the ability for scientific and technological innovation and transfer is poor. Therefore, the city's economic resilience is poor, and its ability to sustain economic development needs to be improved.

During the study period (2004–2016), the opportunity fairness index of economic resilience in different urban agglomerations varied greatly. Nonetheless, the nationwide average opportunity fairness index did not change greatly, from an average of 0.93 in 2004 to 0.92 in 2016, and the overall performance was unfair. At the end of the study, the economic resilience opportunity fairness index of the five urban agglomerations in the South-Central Liaoning, the Yangtze River Delta, the West side of the Straits, the Chengdu-Chongqing, and the North Slopes of the Tianshan Mountain was greater than 1. This indicated that the economic resilience of these urban agglomerations is small, and each city is in the development of urban agglomerations. A fairer opportunity is observed, and, thus, the overall opportunity for the economic resilience of these urban agglomerations is fair.

In particular, the economic resilience of the Yangtze River Delta urban agglomeration moved from non-fairness to fairness during the research period. The Yangtze River Delta urban agglomeration with Shanghai as the core is the most developed urban agglomeration in China, and is internationally recognized as such. In urban agglomerations, the internal UER is balanced, and each city can obtain relatively equal development opportunities. The economic resilience of the Beijing-Tianjin-Hebei and the Pearl River Delta urban agglomerations, which are the three major urban agglomerations in China, have not been fair during the research period. Although the opportunity index is high, it is not conducive to the sustainable economic development of urban agglomerations. Whether it is from the echelon structure of economic development or the economic relationship with the central city, the Yangtze River Delta urban agglomeration is superior to the Beijing-Tianjin-Hebei and the Pearl River Delta urban agglomeration, so it also has a more balanced economic resilience.

In addition, the economic resilience of the 12 urban agglomerations in Central Shanxi, Hu-Bao-E-Y, Harbin-Changchun, Shandong Peninsula, Central Henan, Middle Reaches of Yangtze River, Beibu Gulf, Central Guizhou, Central Yunnan, Guanzhong Plain, Lanzhou-Xining, and Ningxia is not fair. The opportunity fairness index of economic resilience needs to be improved in these areas. The economic resilience of most urban agglomerations in the country is variable across geographic areas, with higher values within the eastern coast. If this is not addressed, it will seriously restrict the improvement of the sustainable development ability of these urban agglomerations.

4. Discussion and Conclusions

Based on the evolutionary theory of UER, this paper considers that UER is a complex system composed of multiple dimensions, including urban economic growth, opening up, social development, environmental protection, natural conditions, and technological innovation. Our results show that cities in China have been developing to withstand external environmental impacts through its dynamic evolution process, thereby achieving sustainable development of the urban economy. Some key findings are presented and discussed below.

First, our results show a single peak distribution of the UER in Chinese cities from 2004 to 2016, with a low UER in a large number of cities and an overall low value in all cities. This single-peak pattern remains unchanged from 2004 to 2016, with a small variation in the peak value and a reduced difference between the peak and low values in later years. This result indicates clear spatial heterogeneity and non-equilibrium in economic resilience across cities in China. The spatial variation of the UER shows that the top 25% of cities with comprehensive economic resilience are located in the eastern coastal areas and the northern coastal areas of China, while the bottom 25% of the cities are mostly located in western China. China's UER remains at a low level for much of the study period, which is not conducive to the high-quality growth and sustainable development of its economy. Therefore, in the future, it is necessary to implement a regionally coordinated development strategy and give full flexibility to utilize the comparative advantages of each city. It is anticipated that this will promote the development of each city towards the direction of high-quality and sustainable development.

Second, the economic resilience opportunity index of the 19 urban agglomerations increased over time, and the economic resilience opportunity curve largely follows that AB curve as illustrated in Sun (2018) (Figure 1). Cities with higher economic resilience within an urban agglomeration are more likely to obtain development space than those with lower economic resilience. In China, large spatial variation exists in the economic resilience opportunity index in cities across various urban agglomerations. The four urban agglomerations in China—the Yangtze River Delta, Chengdu-Chongqing region, the Pearl River Delta, and the Beijing-Tianjin-Hebei region—have the highest economic resilience opportunity index, followed by the nine urban agglomerations of Hu-Bao-E-Yu, Harbin-Changchun, South Central Liaoning, West side of the Straits, Central Henan, Middle Reaches of Yangtze River, Guanzhong Plain, Shandong Peninsula, and Beibu Gulf as the second-tier regions, in terms of their level of economic resilience. Six other urban agglomerations, including Central Shanxi, Central Guizhou, Central Guizhou, Lanzhou-Xining, Ningxia, and North of the Tianshan Mountain region, are ranked at the third-tier with lower economic resilience. In order to reduce the differences across the different tiers of cities and improve the overall economic resilience of Chinese cities, it is critical to optimize and further develop the urban agglomerations in the eastern region. Government policies should consider measures to (1) maintain a trend toward sustainable development in the eastern urban agglomerations, (2) foster and expand the urban agglomerations in the central and western regions, (3) break the regional blockade to support regional development and improve overall economic resilience.

Third, the economic resilience opportunity index of each urban agglomeration varied significantly over time (2004–2016). However, the average opportunity fairness index amongst all urban agglomerations decreased marginally from 0.93 in 2004 to 0.92 in 2016. There is substantial inequality amongst cities in almost all urban agglomerations. A marginal difference in economic resilience exists in some urban agglomerations, such as the South-Central Liaoning, Yangtze River Delta, the West side of Straits, Chengdu-Chongqing, and North of the Tianshan Mountain region; these regions show greater e quity in the equality of economic development opportunities across different cities within the urban agglomeration. On the other hand, substantial inequalities exist in other urban agglomerations, such as the two major ones in China: Beijing-Tianjin-Hebei and the Pearl River Delta urban agglomerations. Compared with the other major urban agglomeration—the Yangtze River Delta urban agglomeration—the opportunities for economic development of small cities within those two major urban agglomerations are less favorable, and it is not as easy to gain development space as it is for other larger cities in these urban agglomerations.

Accordingly, there are opportunities in China to build world-class urban agglomerations in the Beijing-Tianjin-Hebei region and the Pearl River Delta. This will continuously improve the competition of those urban agglomerations. We suggest that future policy in China should not only foster a new competitive advantage for existing cities and urban agglomerations, to improve the system and policy environment and reduce administrative intervention, but also to create greater equality across cities within the urban agglomerations. A friendly environment is better to enhance the ability of the economy to withstand risks and sustainable development. We should establish and improve the coordination mechanism for the development of urban agglomerations, and promote the coordinated division of industry, the division of labor, infrastructure, ecological protection, and environmental governance across cities, to achieve efficient and integrated development of urban agglomerations.

The study contributes to advancing the concept, assessment, and methodology of UER and how this can be applied to assess the spatial and temporal variation of Chinese cities and urban agglomerations. The methodology developed in this research can also be applied in other cities and regions to test its re-applicability and to understand the UER in different contexts. Further research would be required to explore and understand the formation mechanism of UER and potentially provide an early warning mechanism of economic shock in Chinese cities. This will be the main direction for future expansion of this research.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Urban economic resilience ranking in China from 2004 to 2016.

City	2004		2016		City	2004		2016		City	2004		2016	
	Score	Rank	Score	Rank		Score	Rank	Score	Rank		Score	Rank	Score	Rank
Beijing	0.7288	1	0.7630	1	Ganzhou	0.0508	70	0.0545	97	Jingdezhen	0.0235	234	0.0372	193
Shanghai	0.6683	2	0.6980	2	Suqian	0.0445	84	0.0545	98	Fangchengang	0.0158	276	0.0372	194
Shenzhen	0.3307	6	0.4421	3	Jiujiang	0.0441	85	0.0544	99	Shaoyang	0.0352	127	0.0369	195
Suzhou	0.4704	3	0.4343	4	Longyan	0.0320	152	0.0538	100	Heyuan	0.0319	154	0.0368	196
Chongqing	0.4120	4	0.4009	5	Xinyu	0.0253	207	0.0538	101	Chuzhou	0.0300	174	0.0368	197
Tianjin	0.3578	5	0.3916	6	Xiangtan	0.0360	120	0.0538	102	Hengshui	0.0313	162	0.0367	198
Guangzhou	0.2657	7	0.3234	7	Lishui	0.0368	111	0.0537	103	Fuyang	0.0346	132	0.0366	199
Chengdu	0.2013	12	0.2763	8	Dezhou	0.0397	97	0.0536	104	Liaoyuan	0.0189	266	0.0365	200
Hangzhou	0.2093	10	0.2543	9	Rizhao	0.0350	128	0.0529	105	Yingtan	0.0188	267	0.0364	201
Nanjing	0.2093	9	0.2490	10	Changde	0.0396	99	0.0528	106	Yiyang	0.0302	173	0.0364	202
Nantong	0.2255	8	0.2639	11	Quzhou	0.0345	133	0.0527	107	Baoji	0.0242	224	0.0363	203
Wuhan	0.1856	13	0.2234	12	Liuan	0.0313	161	0.0526	108	Xianyang	0.0255	204	0.0362	204
Changzhou	0.2175	11	0.2029	13	Hengyang	0.0445	83	0.0524	109	Yulin	0.0322	149	0.0361	205
Qingdao	0.1630	16	0.1972	14	Xining	0.0378	106	0.0520	110	Wulanchabu	0.0252	209	0.0360	206
Yangzhou	0.1705	14	0.1876	15	Xinxiang	0.0409	95	0.0518	111	Chizhou	0.0267	192	0.0360	207
Xian	0.1601	17	0.1842	16	Yueyang	0.0359	121	0.0516	112	Deyang	0.0229	238	0.0359	208
Ningbo	0.1458	18	0.1815	17	Shaoguan	0.0383	105	0.0512	113	Beihai	0.0205	254	0.0358	209
Wuxi	0.1233	22	0.1678	18	Datong	0.0431	88	0.0510	114	Fuzhou	0.0299	178	0.0358	210
Yancheng	0.1670	15	0.1658	19	Maoming	0.0410	94	0.0509	115	Tianshui	0.0341	139	0.0356	211
Dongguan	0.1273	19	0.1570	20	Benxi	0.0308	165	0.0508	116	Chaozhou	0.0258	201	0.0354	212
Changzhou	0.1137	26	0.1549	21	Hulunbeier	0.0315	159	0.0507	117	Xianyang	0.0245	220	0.0351	213
Zhengzhou	0.1244	21	0.1507	22	Putian	0.0338	142	0.0506	118	Chaoyang	0.0264	197	0.0350	214
Zhenjiang	0.1224	23	0.1489	23	Zaozhuang	0.0354	125	0.0503	119	Puyang	0.0257	202	0.0347	215
Foshan	0.1031	32	0.1482	24	Yingkou	0.0319	153	0.0499	120	Huainan	0.0268	191	0.0343	216
Dalian	0.1164	25	0.1428	25	Zhenjiang	0.0411	92	0.0498	121	Hanzhong	0.0274	188	0.0340	217

Table A1. *Cont.*

City	2004		2016		City	2004		2016		City	2004		2016	
	Score	**Rank**	**Score**	**Rank**		**Score**	**Rank**	**Score**	**Rank**		**Score**	**Rank**	**Score**	**Rank**
Xiamen	0.1059	31	0.1374	26	Guilin	0.0411	93	0.0497	122	Jingzhou	0.0296	180	0.0343	218
Jinan	0.1097	29	0.1374	27	Zhaoqing	0.0365	113	0.0490	123	Baishan	0.0185	268	0.0340	219
Shenyang	0.1122	28	0.1340	27	Suzhou	0.0345	134	0.0488	124	Huludao	0.0293	181	0.0337	220
Hefei	0.1079	30	0.1330	29	Zhangjiajie	0.0415	91	0.0487	125	Bayanzhuoer	0.0155	278	0.0338	221
Huaian	0.1264	20	0.1296	30	Sanming	0.0265	196	0.0486	126	Yizhou	0.0300	175	0.0337	222
Harbin	0.1130	27	0.1284	31	Bengbu	0.0359	122	0.0483	127	Shizuishan	0.0148	282	0.0333	223
Zhouhai	0.0732	46	0.1236	32	Mudanjiang	0.0361	118	0.0479	128	Bozhou	0.0310	163	0.0332	224
Erduosi	0.0433	87	0.1235	33	Fushun	0.0300	177	0.0479	129	Longnan	0.0303	170	0.0332	225
Chuangchun	0.0970	33	0.1208	34	Liaocheng	0.0365	114	0.0474	130	Qinzhou	0.0269	190	0.0329	226
Lianyungang	0.1171	24	0.1182	35	Jiaozuo	0.0306	167	0.0469	131	Zhangye	0.0253	208	0.0329	227
Fuzhou	0.0889	35	0.1155	36	Shuozhou	0.0263	198	0.0468	132	Dingxi	0.0330	145	0.0323	228
Shaoxing	0.0836	37	0.1149	37	Binzhou	0.0358	123	0.0465	133	Loudi	0.0240	229	0.0322	229
Zhongshan	0.0772	40	0.1110	38	Anyang	0.0368	110	0.0461	134	Tieling	0.0249	214	0.0321	230
Kunming	0.0909	34	0.1095	39	Jiayuguan	0.0114	285	0.0460	135	Baishan	0.0246	219	0.0320	231
Yantai	0.0729	45	0.1033	40	Shiyan	0.0355	124	0.0459	136	Huaibei	0.0219	244	0.0320	232
Nanchang	0.7710	41	0.1108	41	Tongliao	0.0242	225	0.0455	137	Guyuan	0.0308	166	0.0317	233
Wenzhou	0.0843	36	0.1006	42	Kaifeng	0.0332	144	0.0451	138	Jieyang	0.0233	236	0.0314	234
Wulumuqi	0.0720	47	0.1005	43	Xuchang	0.0308	164	0.0451	139	Hechi	0.0302	172	0.0313	235
Taiyuan	0.0797	39	0.1003	44	Chifeng	0.0340	140	0.0447	140	Leshan	0.0218	246	0.0312	236
Xuzhou	0.0817	38	0.0991	45	Huangshan	0.0303	171	0.0442	141	Yibin	0.0240	228	0.0308	237
Baotou	0.0505	71	0.0984	46	Qingyuan	0.0346	135	0.0441	142	Lvliang	0.0247	216	0.0307	238
Huhehaote	0.0606	60	0.0965	47	Mianyang	0.0385	102	0.0440	143	Zigong	0.0204	256	0.0306	239
Quanzhou	0.0783	44	0.0964	48	Jiuquan	0.0249	215	0.0439	144	Nanchong	0.0279	187	0.0305	240
Jiaxing	0.0694	49	0.0960	49	Zhangjiakou	0.0373	108	0.0439	145	Qujing	0.0285	183	0.0304	241
Guiyang	0.0763	42	0.0958	50	Songyuan	0.0265	195	0.0439	146	Luzhou	0.0245	221	0.0303	242
Dongying	0.0321	150	0.0920	51	Zhumadian	0.0384	103	0.0438	147	Shanwei	0.0248	215	0.0300	243
Weihai	0.0530	67	0.0919	52	Qiqihaer	0.0395	101	0.0436	148	Fuxin	0.0238	230	0.0295	244
Taizhou	0.0640	56	0.0913	53	Changzhi	0.0324	147	0.0433	149	Jixi	0.0236	231	0.0294	245
Shijiazhuang	0.0760	43	0.0912	54	Yangquan	0.0292	182	0.0433	150	Qitaihe	0.0243	223	0.0292	246
Taizhou	0.0674	50	0.0879	55	Anqing	0.0360	118	0.0430	151	Luohe	0.0198	258	0.0292	247
Zibo	0.0574	65	0.0877	56	Xinyang	0.0366	112	0.0426	152	Heihe	0.0252	210	0.0292	248
Huizhou	0.0655	53	0.0867	57	Pingdingshan	0.0354	126	0.0424	153	Siping	0.0211	249	0.0292	249
Lanzhou	0.0663	52	0.0862	58	Shangqiu	0.0371	109	0.0423	154	Chongzuo	0.0208	251	0.0291	250
Jinhua	0.0650	55	0.0860	59	Heze	0.0383	104	0.0422	155	Suizhou	0.0196	261	0.0291	251
Wuhu	0.0608	59	0.0859	60	Jinzhou	0.0317	157	0.0421	156	Yunfu	0.0318	156	0.0291	252
Weifang	0.0665	51	0.0839	61	Jinzhong	0.0339	141	0.0419	157	Baiyin	0.0221	241	0.0289	253
Tangshan	0.0598	61	0.0839	62	Shangrao	0.0377	106	0.0418	158	Lijiang	0.0234	236	0.0284	254
Nanning	0.0704	48	0.0827	63	Xiaogan	0.0347	130	0.0417	159	Pingliang	0.0240	227	0.0284	255
Jinlin	0.0655	54	0.0806	64	Tonghua	0.0298	179	0.0415	160	Suihua	0.0263	199	0.0283	256
Haikou	0.0638	57	0.0798	65	Nanping	0.0266	194	0.0414	161	Wuzhou	0.0295	262	0.0282	257
Huzhou	0.0543	66	0.0785	66	Huangshi	0.0250	211	0.0413	162	Jinchang	0.0108	286	0.0281	258
Luoyang	0.0614	58	0.0768	67	Jincheng	0.0283	185	0.0413	163	Dazhou	0.0235	232	0.0280	259
Zhoushan	0.0429	89	0.0763	68	Yangjiang	0.0246	218	0.0411	164	Guigang	0.0266	193	0.0279	260
Yichang	0.0433	86	0.0731	69	Laiwu	0.0263	200	0.0408	165	Hebi	0.0147	284	0.0277	261
Lasa	0.0586	63	0.0715	70	Dandong	0.0305	169	0.0406	166	Guangan	0.0206	253	0.0273	262
Jining	0.0575	64	0.0695	71	Meizhou	0.0363	117	0.0405	167	Shuangyashan	0.0214	247	0.0270	263
Yinchuang	0.0473	79	0.0694	72	Xuancheng	0.0305	168	0.0505	168	Tongchuan	0.0157	277	0.0268	264
Daqing	0.0255	205	0.0693	73	Yongzhou	0.0304	116	0.0404	169	Baoshan	0.0235	233	0.0267	265
Kelamayi	0.0141	284	0.0685	74	Liaoyang	0.0244	222	0.0404	170	Wuwei	0.0205	255	0.0265	266
Xiyang	0.0472	80	0.0682	75	Tongling	0.0195	263	0.0404	171	Guangyuan	0.0241	226	0.0264	267
Linxi	0.0592	62	0.0673	76	Jingmen	0.0254	206	0.0401	172	Ankang	0.0213	248	0.0263	268
Langfang	0.0457	82	0.0667	77	Panzhihua	0.0149	281	0.0401	173	Baise	0.0219	243	0.0262	269

Table A1. *Cont.*

City	2004		2016		City	2004		2016		City	2004		2016	
	Score	Rank	Score	Rank		Score	Rank	Score	Rank		Score	Rank	Score	Rank
Anshan	0.0491	74	0.0666	78	Sanmenxia	0.0224	240	0.0398	174	Hezhou	0.0219	242	0.0258	270
Sanya	0.0474	78	0.0662	79	Anshun	0.0344	135	0.0396	175	Zhongwei	0.0211	250	0.0255	271
Taian	0.0481	77	0.0646	80	Ezhou	0.0167	273	0.0395	176	Zhaotong	0.0225	239	0.0521	272
Jiangmen	0.0489	75	0.0636	81	Jiamusi	0.0318	155	0.0393	177	Bazhong	0.0256	203	0.0250	273
Wuhai	0.0205	254	0.0601	82	Yanan	0.0207	243	0.0392	178	Meishan	0.0175	270	0.0243	274
Binzhou	0.0406	96	0.0593	83	Pingxiang	0.0249	212	0.0392	179	Qingyang	0.0171	272	0.0243	275
Liuzhou	0.0396	98	0.0579	84	Xingtai	0.0343	137	0.0391	180	Puer	0.0233	237	0.0242	276
Baoding	0.0520	68	0.0575	85	Ningde	0.0246	217	0.0391	181	Laibin	0.0197	259	0.0239	277
Handan	0.0501	72	0.0575	86	Jian	0.0344	136	0.0390	182	Ziyang	0.0162	274	0.0238	278
Panjin	0.0284	184	0.0571	87	Yichun	0.0320	151	0.0389	183	Yanan	0.0199	267	0.0235	279
Zhangzhou	0.0395	100	0.0569	88	Huanggang	0.0347	129	0.0386	184	Lincang	0.0150	279	0.0234	280
Nanyang	0.0516	69	0.0568	89	Liupanshui	0.0274	189	0.0384	185	Shangluo	0.0196	260	0.0223	281
Shantou	0.0483	76	0.0568	90	Yuncheng	0.0341	138	0.0383	186	Yichun	0.0192	265	0.0222	282
Qinhuangdao	0.0461	81	0.0565	91	Chengde	0.0281	186	0.0382	187	Neijiang	0.0158	279	0.0221	283
Zunyi	0.0496	73	0.0559	92	Yuxi	0.0218	245	0.0381	188	Hegang	0.0173	269	0.0220	284
Zhouzhou	0.0365	115	0.0558	93	Linfen	0.0316	158	0.0381	189	Suining	0.0174	271	0.0219	285
Maanshan	0.0335	143	0.0556	94	Zhoukou	0.0314	160	0.0381	190	Wuzhong	0.0150	280	0.0204	286
Yulin	0.0300	176	0.0555	95	Weinan	0.0323	148	0.0375	191					
Cangzhou	0.0427	90	0.0554	96	Haihua	0.0330	146	0.0373	192					

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