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Analysis of the Temporal and Spatial Pattern and Convergence Characteristics of High-Quality Sustainable Economic Development of Urban Agglomeration

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Abstract: Based on the sample data of 149 cities in ten major urban agglomerations from 2004 to 2019, the entropy method, Dagum Gini coefficient, and three-dimensional kernel density estimation method are used to calculate and describe the spatial pattern of the high-quality, sustainable economic development of these ten major urban agglomerations. We then use the spatial econometric model to estimate the β convergence trend within the urban agglomerations and among the urban agglomerations at different levels. Our main findings include the following: First, the urban agglomeration tends to develop a high-quality economy, but the gap between the urban agglomerations can be large. Second, although the gap within the overall group of urban agglomerations is expanding, the gap between high-quality individuals and the average is constantly shrinking; the gap between groups is still the leading cause of the spatial gap, with a contribution rate of 70.51%. Third, all urban agglomerations have an absolute and conditional β convergence trend, and the convergence speed presents the characteristics of "high level slow, low level fast". Government intervention, financial development, urbanization, and human capital contribute to the high-quality, sustainable economic development of each urban agglomeration. There is a heterogeneous influence; there is also absolute and conditional β convergence among urban agglomerations at all levels, and the convergence rate presents a gradient characteristic of "third level > second level > first level", and by balancing the financial relationships between city groups within each level, development differences can promote the dynamic coordination of high-quality, sustainable economic development rates.

Keywords: urban agglomeration; high-quality sustainable economic development; spatial dynamic characteristics; regional balanced development

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1. Introduction

Countries in Europe, North America, and Asia started the construction of urban agglomerations earlier, such as the New York City Agglomeration, London–Liverpool Agglomeration, Paris Agglomeration, and Tokyo Agglomeration [1]. Scholars at home and abroad are increasingly paying attention to urban agglomeration during construction [2–5]. From the middle and late 20th century to now, research has been conducted in urban agglomeration economy [6–8], the social governance of urban agglomeration [9], and the urban agglomeration ecological environment [10–12]. The construction of urban agglomerations in developed countries such as the United States, Britain, France, and Japan has been effective, providing policy insights on economic development through urban agglomerations. However, there is a gap in the development level of urban agglomerations among countries, and due to the differences in economic, political, cultural, geographical, and other factors, some developing countries do not have the conditions to directly imitate the successful experience of urban agglomerations in developed countries. As a result, there are still many problems in developing urban agglomerations in developing countries. Taking China as an example, although China has created a miracle of high-speed growth and is shifting from high-speed growth to high-quality development, it still has problems such as unbalanced economic development between the North and the South and large gaps in regional innovation capabilities. This leads to the promotion of balanced regional development as the core task of China's regional development [13]. The Chinese government is also concerned about this issue, with particular emphasis on the ability of urban agglomerations to gather factors. It aims to use the central city's growth to change the speed and mode of the overall economic growth in the region [14].

The highest spatial organization form of the city, the urban agglomeration, is the main form of China's new urbanization, and is also an important carrier to expand development space, promote the balanced development of the regional economy, and release the potential of economic development. However, due to the large differences in resource endowments and economic development stages among China's regions, there is a big gap in each central city's growth pole radiation effect in promoting high-quality economic development [15]. This hinders the high-quality, sustainable development process of the overall economy of urban agglomerations. Then, what is the difference between the high-quality economic development of China's urban agglomerations? Answering this question can provide more profound characteristic facts and a realistic basis for China to study the high-quality development of the regional economy from the perspective of urban agglomeration in the later period. It can also provide Chinese experience for other developing countries to promote the coordinated development of the regional economy.

The analysis of the spatial and temporal differences and dynamic evolution characteristics of the economic development quality of urban agglomerations must be based on the accurate measurement of the development quality. In the literature, data envelopment analysis is used to measure total factor productivity and as a proxy variable of the quality of economic development [16]. However, since total factor productivity only presents technology, scale, and labor efficiency, it cannot fully reflect the new requirements of sustainable development, rendering research results impractical. Considering the change in employment rate, Wu et al. revised the traditional share change analysis method and measured the part of the change in economic growth quality caused by the shift in industrial structure [17]. This improvement further presents the dynamic economic growth quality change process based on only focusing on total factor productivity. However, the measurement is only reflected in the level of industrial structure change and fails to fully reflect the five development concepts of innovation, green development, coordination, openness, and sharing. Compared with the measurement of a single dimension of total factor productivity, it is more effective to measure the quality of economic development from the three dimensions of conditions, processes, and results of economic growth [18]. However, the principal component analysis method will cause comprehensive evaluation errors due to the correlation between the original indicators, and the index selection pays more attention to economic growth rather than economic development. The five dimensions of innovation, coordination, green development, openness, and sharing are used to measure the quality of economic development [19]. However, the high-quality development of China's urban agglomerations has not been evaluated, and the problem of changes in the pattern of regional economic growth cannot be answered.

The differences in regional economic development and spatial patterns have always been a research focus [20]. Existing research has focused on regional economic growth differences [21] or the influencing factors [22] of regional economic disparities, and there is a lack of literature directly studying the differences in the quality of economic development in urban agglomerations. Although the regional differences between China's eight major urban agglomerations are analyzed [23], only the regional imbalance and stepped distribution characteristics of urban agglomerations are analyzed, and the inter-group differences of urban agglomerations and the dynamic changes of high-quality development are not analyzed. This makes it impossible to objectively identify the differences in high-quality economic development among urban agglomerations. Ref. [24] analyzed the resource-carrying capacity of the Yangtze River Economic Belt and made some contributions to the sustainable development of urban agglomerations. However, they only studied the status of the Yangtze River Economic Belt and lacked comparative analysis with other urban agglomerations. In addition, some literature has carried out dynamic evolution analysis on the differences in the quality of economic development among the four major plates of China's eastern, central, western, and northeastern regions at the provincial level and concluded that there are differences in the innovation, coordination, sustainability, openness, and sharing development levels of each plate [25]. The high-quality economic development of China's four major sectors is the key to inter-provincial coordination. However, due to the independence of the provincial financial system, the role of the provincial growth pole is often restricted by administrative division. Some studies have also taken China's prefecture-level-and-above cities as research units to explore the economic spatial differences of the four major sectors, and pointed out that there is a "club convergence" phenomenon in China's urban economic development, and the neighborhood environment of the city has a greater impact on urban economic development [17]. However, some scholars are skeptical of this conclusion, believing that the multi-center urban spatial development strategy cannot narrow the regional economic gap. At the same time, the core cities in the single-center region can share the benefits of agglomeration through labor mobility and narrow the regional economic gap [18]. In other words, the economic development in the urban agglomeration is easier to achieve "club convergence". Then, does the quality of economic development of urban agglomerations also have spatial convergence? Is this spatial convergence consistent across urban agglomerations? Regarding the above two issues, scholars have proved that there are differences in the ability of industrial agglomeration and factor agglomeration in urban agglomerations, which leads to spatial heterogeneity in the quality of economic development [20]. However, the convergence difference in the economic development quality of urban agglomerations has not been analyzed, which makes it challenging to identify the constraints of coordinated development in different urban agglomerations, thus hindering the overall high-quality development of the regional economy.

The above analysis shows that previous studies have significantly contributed to urban agglomerations and high-quality economic development, but there are still many deficiencies. Specifically, first, the measurement method of economic growth quality that emphasizes productivity is unsuitable for China's current development. Therefore, it is urgent to combine the development concepts of innovation, coordination, green development, openness, and sharing; expand the current measurement indicators of the quality of economic development of urban agglomeration; and improve the existing comprehensive evaluation methods to measure the economic development quality in China's prefecture-level cities scientifically. Second, there are many studies on the spatial differences in high-quality economic development in the four major plates of east, central, west, and northeast China. Still, there is a lack of research on the differences in high-quality economic development among urban agglomerations. Therefore, it is not easy to explore the growth pole effect of core cities. Third, most studies focus on the static spatial differences of high-quality regional economy development and lack the analysis of dynamic convergence characteristics of the high-quality development of an urban agglomeration economy. Therefore, it is unfavorable to identify the core factors that impede the high-quality development of urban agglomerations. In consideration of the above reasons, firstly, based on high-quality economic development, this paper incorporates the connotation of sustainable development, selects scientific indicators from the five dimensions of innovative, green, coordinated, open, and shared development, and uses the entropy method to comprehensively measure the economic development quality index of ten urban agglomerations in China. Therefore, this paper comprehensively evaluates the ability of high-quality sustainable development of ten urban agglomerations in China, and compares and analyzes the differences in high-quality development of different urban agglomerations in the two dimensions of time and space to provide a basis for further analysis. Secondly, this paper uses the Dagum Gini coefficient to measure the intra-group and inter-group differences of urban agglomerations, shows the spatial relative heterogeneity of high-quality development of urban agglomerations, explores the sources of spatial differences of urban agglomerations, and provides a practical basis for policy formulation to narrow the spatial differences of urban agglomerations. Thirdly, this paper uses kernel density estimation to identify the dynamic evolution characteristics and differences of high-quality development of urban agglomerations, predicts the dynamic trend of high-quality development of urban agglomerations in the future, and explores the possible pressures and obstacles in the process of high-quality development. Finally, this paper uses a variety of spatial econometric models to determine the differences in the convergence patterns of urban agglomerations. Relying on comparative analysis, this paper identifies the constraints that hinder the synergy within urban agglomerations and provides theoretical support for expanding the "core–periphery" theory in a more microscopic unit [26]. At the same time, this study examines the strategic effect of China's economic integration and provides Chinese experience for other developing countries to promote high-quality and sustainable economic development.

2. Methods and Data

In this part, this study designs four methods to measure the high-quality economic development level, spatial pattern, dynamic evolution trend, and spatial convergence state of the ten major urban agglomerations, in order to deeply analyze the spatial and temporal pattern and convergence characteristics of the high-quality development of China's urban agglomerations, as shown in Figure 1. In Figure 1, in section I, this study designs the entropy weight method and Delphi method to measure the high-quality economic development level of each urban agglomeration, which is used to describe the trend of high-quality development level of each urban agglomeration over time. In section II, this study uses the Dagum Gini coefficient method to measure the differences between urban agglomerations, the differences between individuals within urban agglomerations, and the sources of overall differences in urban agglomerations, showing the spatial pattern of urban agglomerations. In section III, this study uses the kernel density estimation method to calculate and present the dynamic development trend of each urban agglomeration in the future, compares and analyzes the dynamic changes of different urban agglomerations, and shows the dynamic evolution trend of the spatial pattern of each urban agglomeration. In section IV, this study constructs the spatial econometric model to analyze the absolute convergence, conditional convergence, and club convergence of ten urban agglomerations and shows the dynamic convergence characteristics of each urban agglomeration.

2.1. Indexes System and Data Sources

Based on the definition of high-quality economic development by scholars [27], this paper argues that the high-quality, sustainable development of urban agglomeration economy is based on the five development concepts, forming a development state of urban agglomeration with innovative development power source, coordinated development space characteristics, green development natural form, open development international pattern, and sharing a good situation of development. Under this definition, this paper constructs a measurement index system for high-quality, sustainable economic development from the five dimensions of innovation, green development, coordination, openness, and sharing [19,28], as shown in Table 1.

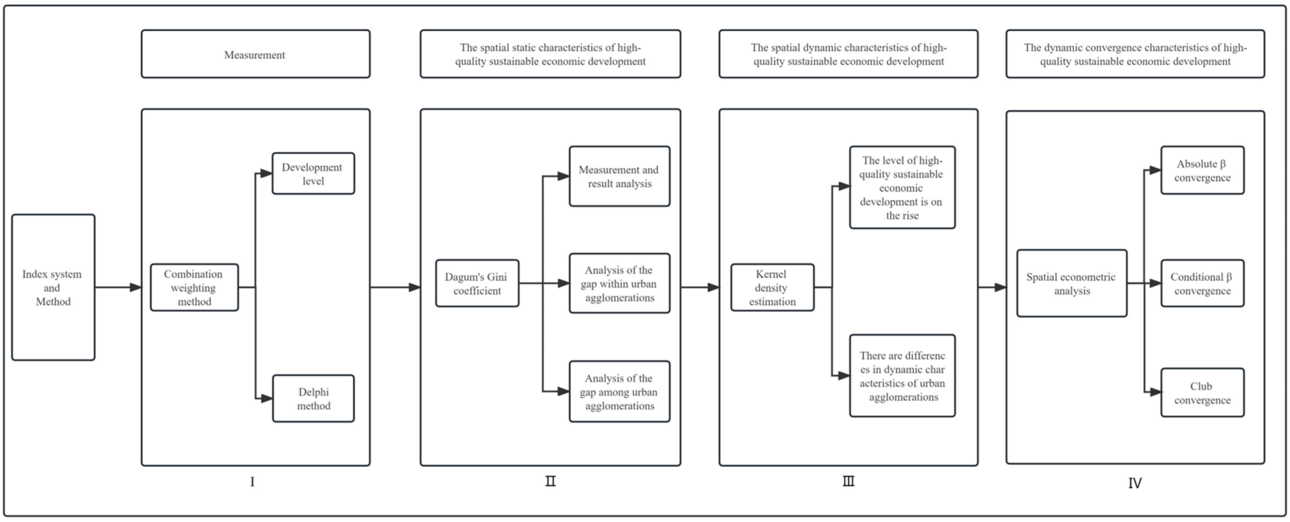


Figure 1. The flow chart of the methods.

Table 1. Evaluation index system for the level of high-quality, sustainable economic development.

First-Grade Index	Second-Grade Index	Third-Grade Index	Unit	Weight	Index Direction
Innovative Development	Innovation Input	Research Funding Intensity	%	0.0499	+
		Researcher Input Intensity	Per	0.0351	+
	Innovation Output	Grant Number	Ind	0.1149	+
Coordinated Development	Industrial Development Coordination	Rationalization of Industrial Structure	%	0.0369	-
		Optimization of Industrial Structure	%	0.0855	+
		Proportion of Producer Services	%	0.0776	+
Green Development	Green Lifestyle	Urban Green Coverage Rate	%	0.0460	+
		Innocuous Disposal Rate of Domestic Garbage	%	0.0441	+
	Energy Consumption	Energy Consumption Per Unit of GDP	M^3/Million CNY	0.0324	-
		Electricity Consumption Per Unit of GDP	KWH/Million CNY	0.0326	-
	Environmental Governance	Comprehensive Utilization Rate of General Industrial Solid Waste	%	0.0449	+
Open Development	Foreign Trade	Proportion of Total Export–Import to GDP	%	0.1294	+
	Foreign Capital Use	FDI	%	0.0706	+
Sharing Development	Economic Sharing	Per Capita GDP	CNY/PP	0.0413	+
		Public Service Expenditure Per CAPITA	CNY/PP	0.0564	+
	Social Sharing	Number of Hospital Beds Per Capita	Ind/Million People	0.0257	+
		Educational Fund	Million CNY	0.0766	+

Note: "+" indicates that each index has a positive effect on high-quality economic development. "-" indicates that each index has a negative effect on high-quality economic development.

After analyzing the number and name of China's urban agglomerations in the past 40 years of reform and opening up, Ref. [29] shows that there have been 19 urban agglomerations in China since 2015. These urban agglomerations are the Yangtze River Delta, the Pearl River Delta (Guangdong, Hong Kong, and Macao), Beijing–Tianjin–Hebei, the middle reaches of the Yangtze River, Chengdu–Chongqing, the west bank of the Strait, central and southern Liaoning, the Shandong Peninsula, the Central Plains, Hubao Eyu, Beibu Gulf, Hachang, Guanzhong, Ningxia along the Yellow River, the northern slope of Tianshan Mountains, Jinzhong, Dianzhong, Qianzhong, and Lanxi urban agglomerations. Considering that scholars generally believe that Beijing–Tianjin–Hebei, the middle reaches of the Yangtze River, Guangdong–Hong Kong–Macao, Chengdu–Chongqing, Yangtze River Delta, Central Plains, and Harbin–Changchun urban agglomerations play a vital role in China's regional economic development [30], this study selects the above 7 urban agglomerations from 19 urban agglomerations as the research object of this study. At the same time, considering the crucial role of urban agglomerations in regionally balanced development, this study included the Guanzhong urban agglomeration in the western region and the Liaozhongnan urban agglomeration in the northeastern region in the above seven urban agglomerations, to eliminate the impact of economic development differences in eastern, central, western, and northeastern China on the research results through sample selection. In addition, because the urban agglomeration on the west side of the Strait contains multiple prefecture-level cities in Fujian, Zhejiang, Guangdong, and other provinces, these prefecture-level cities are also included in the sample of urban agglomerations because they are located in the coastal areas and play a vital role in economic development. Finally, this study selected ten urban agglomerations as research samples. In addition, in analyzing the convergence between urban agglomerations, according to the location and resource endowment characteristics of urban agglomerations, this paper divides the ten urban agglomerations into three levels [31]. The first layer includes Guangdong–Hong Kong–Macao, the Yangtze River Delta, and Beijing–Tianjin–Hebei urban agglomerations. The second layer includes the urban agglomerations in the middle reaches of the Yangtze River, the Central Plains, Chengdu–Chongqing, and central and southern Liaoning. The third layer includes Ha-Chang, Guanzhong, and urban agglomerations on the west side of the Strait. The spatial scope of all urban agglomerations is defined as shown in Figure 2. This paper selects prefecture-level cities from 2004 to 2019 as samples. This paper selects the data from 8 years before and after 2012 and carries out a cross-period comparative analysis. The research data of each index are from the China Urban Statistical Yearbook, China Regional Economic Statistical Yearbook, and the statistical yearbooks of various provinces and cities. The missing data in the yearbook were obtained by applying to the municipal statistical department for government affairs disclosure.

2.2. Research Methods

2.2.1. Combination Weighting Method

In the previous measurement, the weighting method was used to reduce the dimension of variables in the five dimensions of innovation, coordination, green development, openness, and sharing [29]. However, due to the different numbers of secondary indicators selected by the five dimensions, the concentration of all secondary indicators will lead to differences in the weight of each dimension, which is not in line with China's five development concepts. Considering that there is no weight difference between innovation, coordination, green development, openness, and sharing in China's five major development concepts, this study uses subjective weighting methods and objective entropy weight methods to measure high-quality economic development [32]. According to expert opinions, the index weights of the five dimensions of innovation development, coordinated development, green development, open development, and shared development are equally weighted, and the total weight of each dimension is set to 0.20. Finally, to empower the secondary indicators of each dimension, this study employs the entropy weight TOPSIS method [33]. The entropy weight TOPSIS method can consider the degree of variation of each measurement index datum, reduce the interference factors of subjective weighting, and compare the relative distance between each measurement object and the optimal scheme and the worst scheme. According to this relative distance ranking, the specific weight of each index is presented. The calculation is simple, and the result is objective and reasonable. Therefore, the combination of the subjective assignment and objective entropy method can not only consider China's five primary development concept needs but also objectively judge China's high-quality, sustainable economic development level. In addition, to facilitate the comparative analysis between different years, this study adds time variables [34], which makes the results more reasonable. The main calculation formula is shown below:

$$Edq_{it} = \sum_{j=1}^{m} W_j \times P_{ijt}, \quad (1)$$

In Equation (1), Edq_{it} represents the high-quality sustainable economic development index of city i in year t. The larger the value, the higher the level of high-quality, sustainable economic development of city i, and vice versa. P_{ijt} is the share of each index in the total index; W_j is the weight of each specific index.

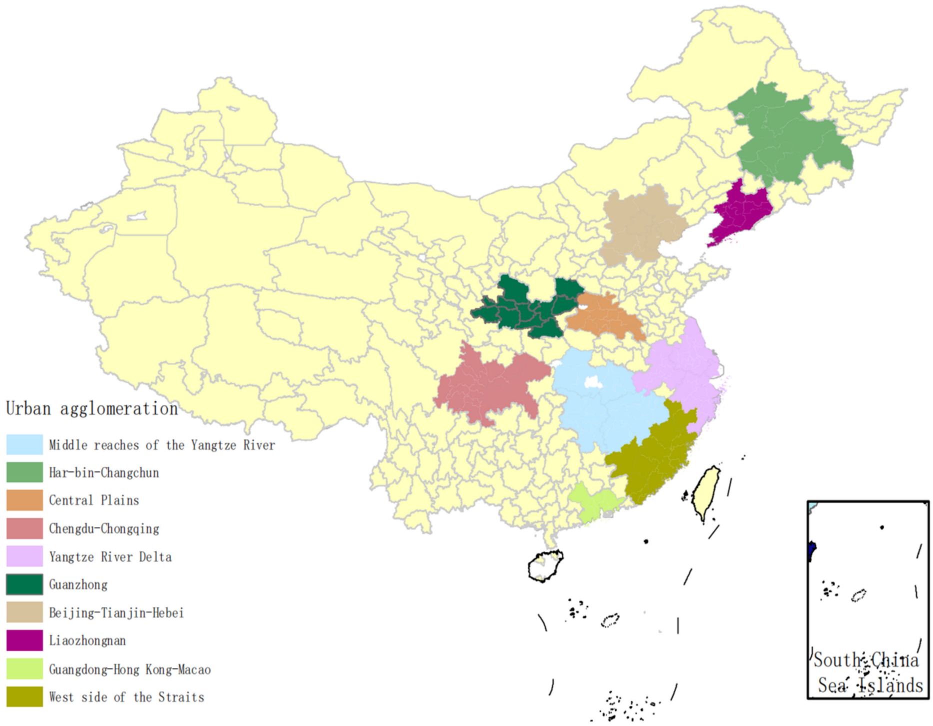


Figure 2. The geographical distribution of the ten largest urban agglomerations.

2.2.2. Dagum's Gini Coefficient

The Dagum Gini coefficient measures the spatial disparity of superior economic growth within urban agglomerations [35]. Compared with the traditional Gini coefficient and Theil index, the Dagum Gini coefficient considers the distribution of sub-samples and cross-overlapping factors. It can more accurately measure the differences within and between urban agglomerations and analyze the sources of spatial gaps in high-quality sustainable economic development of urban agglomerations by decomposition. The calculation is shown below:

$$G = \frac{1}{2\overline{Edq}n^2}\left(\sum_{i=1}^{n}\sum_{r=1}^{n}|Edq_i - Edq_r|\right) = \sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\frac{|Edq_{ji} - Edq_{hr}|}{2n^2\overline{Edq}}, \quad (2)$$

In Equation (2), k represents the total number of urban agglomerations, $j(h)$ is the subscript of urban agglomeration, n represents the number of cities, and i and r are the subscripts of cities. $n_j(n_h)$ is the number of cities in urban agglomeration $j(h)$. $Edq_{ji}(Edq_{hr})$ is the measured value of the high-quality, sustainable economic development index of city $i(r)$ in the $j(h)$ urban agglomeration. $\overline{Edq}$ denotes the average value of the high-quality, sustainable development index of all the investigated cities. G represents the total Gini coefficient, which can be further decomposed into intra-urban-agglomeration, inter-group, and intra-group overlap.

2.2.3. Kernel Density Estimation

To understand how high-quality sustainable economic development is evolving in urban agglomerations, we utilized kernel density estimation results to illustrate this development's location, shape, and flexibility. In this paper, the Gaussian kernel function is used to construct kernel function $K(x)$. The main estimation formulas are shown in Equations (3) and (4). $f(x)$ is the density function of random variable X. N, X_i, and h denotes the number of observations, independent and identically distributed observations, and broadband, respectively.

$$f(x) = (\frac{1}{Nh})\sum_{i=1}^{N} K(\frac{X_i - x}{h}), \tag{3}$$

$$K(x) = (\frac{1}{\sqrt{2\pi}})exp(\frac{-x^2}{2}), \tag{4}$$

2.2.4. Spatial Econometric Model

To measure the convergence and divergence state of high-quality, sustainable economic development of urban agglomerations and identify whether there are dynamic convergence characteristics in the differences of high-quality, sustainable economic development of urban agglomerations and how to narrow the differences of high-quality, sustainable economic development within and across urban agglomerations, the spatial econometric models are constructed below:

$$ln\left(\frac{Edq_{i,t+1}}{Edq_{i,t}}\right) = \alpha + \beta\, ln(Edq_{i,t}) + \rho\sum_{j=1}^{n} w_{ij} ln\left(\frac{Edq_{j,t+1}}{Edq_{j,t}}\right) + \theta\sum_{j=1}^{n} w_{ij} ln\left(Edq_{j,t}\right) + \mu_i + \varphi_t + \varepsilon_{it}\ ;\ \varepsilon_{it} = \lambda\sum_{j=1}^{n} w_{ij}\varepsilon_{jt} + \sigma_{it} \tag{5}$$

$$ln\left(\frac{Edq_{i,t+1}}{Edq_{i,t}}\right) = \alpha + \beta\, ln(Edq_{i,t}) + \rho\sum_{j=1}^{n} w_{ij} ln\,(\frac{Edq_{j,t+1}}{Edq_{j,t}}) + \delta ln X_{i,t+1} + \theta\sum_{j1}^{n} w_{ij} ln\left(Edq_{j,t}\right) + \gamma\sum_{j=1}^{n} w_{ij} ln x_{j,t} + \mu_i + \varphi_t + \varepsilon_{it}, \tag{6}$$

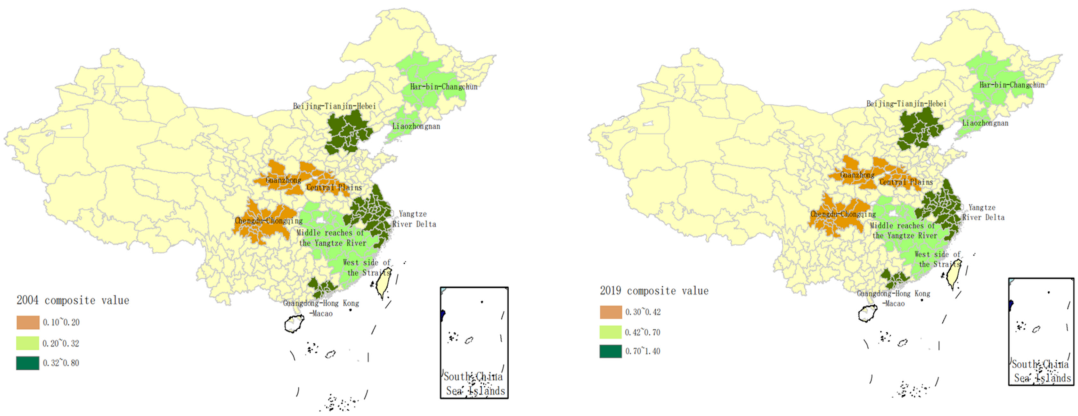
Models (5) and (6) are the general forms of spatial econometric models. In the specific estimation process, the model form must finally be determined by Wald, LM, and L.R. tests. W_{ij} is the i row and j column element of the spatial weight matrix W. The spatial weight matrix is the geographical distance weight matrix, which is calculated by the reciprocal of the difference between the longitude and latitude of the two places. The reason is that externalities such as innovation will decay with geographical distance, and there are geographical distance restrictions on factor mobility. In Model (6) is a set of control variables that represents an essential factor affecting the dynamic convergence of high-quality, sustainable economic development of urban agglomerations.

3. Analysis of Dynamic Convergence Characteristics of High-Quality, Sustainable Economic Development of Urban Agglomerations

3.1. Measurement and Result Analysis of High-Quality, Sustainable Economic Development Level of Urban Agglomerations

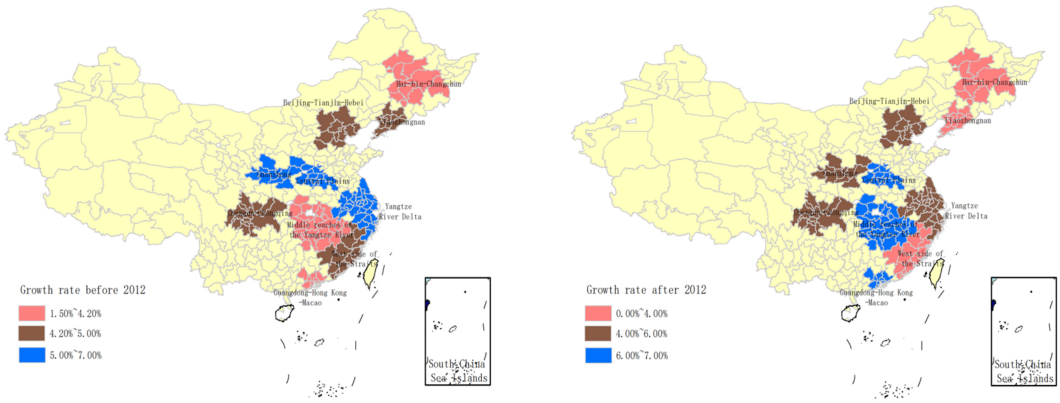
The calculation results of the high-quality, sustainable economic development of urban agglomerations show that the Guangdong–Hong Kong–Macao Greater Bay Area has the highest level of high-quality sustainable economic development. The value is 2.23 times higher than the overall average of 0.4308 (Table A1) and 3.47 times higher than the lowest level in the Guanzhong urban agglomeration (Table A1). The second are the Yangtze River Delta and Beijing–Tianjin–Hebei urban agglomerations. The third are the middle reaches of the Yangtze River, Harbin–Changchun, central and southern Liaoning, and the west coast of the Strait urban agglomeration. Although it is slightly higher than the central plains, Chengdu–Chongqing, and Guanzhong urban agglomerations, it is still lower than the average level of ten urban agglomerations. The results of this study on the high-quality, sustainable development of urban agglomeration economies and the differences between urban agglomerations confirm and expand the previous research. Figure 3 shows that from

2004 to 2019, the high-quality, sustainable economic development level of Guangdong–Hong Kong–Macao, Yangtze River Delta, and Beijing–Tianjin–Hebei urban agglomerations has always been in the first echelon. It can be seen that the eastern coastal cities still have a strong driving force for high-quality, sustainable economic development due to their strong talent-gathering ability and strong innovation capital. Figure 4 shows that before and after 2012, the average level of high-quality, sustainable economic development in Guangdong, Hong Kong, Macao, the Yangtze River Delta, and Beijing–Tianjin–Hebei continued to be in a leading position. The Central Plains, Chengdu–Chongqing, and Guanzhong Plain urban agglomerations continue to be at the end, and there is a big gap with the leading urban agglomerations such as Guangdong, Hong Kong, and Macao. This may be because the quality of life and the level of urbanization in the central and western cities limit high-quality economic development [17]. From the analysis of time trends, the overall high-quality, sustainable economic development level of each urban agglomeration showed an increasing trend year by year from 2004 to 2019, with an average annual growth rate of 4.62% (Table A1). Figure 4 also shows that before and after 2012, the growth rate of high-quality, sustainable economic development changed significantly. Before 2012, the Yangtze River Delta, Central Plains, and Guanzhong urban agglomerations had the fastest average annual growth rate of high-quality sustainable economic development. After 2012, the growth rate of the Yangtze River Delta and Guanzhong urban agglomerations slowed down. Still, the growth rate of the middle reaches of the Yangtze River and the Guangdong–Hong Kong–Macao urban agglomerations jumped from the third echelon to the first echelon. This change may be due to the significant increase in the level of openness and coordinated development of the two major urban agglomerations in the middle reaches of the Yangtze River and Guangdong, Hong Kong, and Macao. The west coast of the Taiwan Strait and the central and southern Liaoning urban agglomeration have been reduced from the second echelon of growth rate to the third echelon. The reason may be that the slow green development of the west coast of the Taiwan Strait and the lack of innovation in central and southern Liaoning have hindered the improvement of the high-quality, sustainable economic development rate of the two urban agglomerations.



(**a**) (**b**)

Figure 3. The classification of the comprehensive index of the high-quality sustainable economic development of the top ten urban agglomerations in 2004 (**a**) and 2019 (**b**).



(**a**) (**b**)

Figure 4. Tiered division of the average annual growth rate of the high-quality, sustainable economic development of the ten major urban agglomerations. (**a**) is the hierarchical division of the average annual growth rate of the high-quality, sustainable economic development of the ten major urban agglomerations before 2012. (**b**) is the hierarchical division of the average annual growth rate of the high-quality, sustainable economic development of the ten major urban agglomerations before 2012.

3.2. Spatial Gap Analysis of High-Quality, Sustainable Economic Development Level of Urban Agglomerations

3.2.1. Analysis of the Gap in High-Quality, Sustainable Economic Development within Urban Agglomerations

Using the Dagum Gini coefficient, the spatial gap of high-quality, sustainable economic development in each urban agglomeration is calculated. The results are shown in Table 2. Table 2 shows that the difference in the level of high-quality sustainable economic development within Beijing, Tianjin, and Hebei is the largest, followed by the Yangtze River Delta and Guangdong, Hong Kong, and Macao. The reason may be that there is a strong polarization effect in the high-quality sustainable economic development level of Beijing, Guangzhou, Shenzhen, Shanghai, and Nanjing, and the radiation effect of the central city has not yet appeared. The difference in the level of high-quality sustainable economic development among cities in the Central Plains urban agglomeration is the smallest, and the mean value of the Gini coefficient is about 3/5 of the overall mean value of the sample. From the analysis of the trend of intra-group differences in urban agglomerations, the average annual growth rate of the Gini coefficient of the sample is 0.64%, indicating that the internal gap of the overall high-quality sustainable economic development of urban agglomerations is expanding year by year. The radiation effect of the central cities of urban agglomerations needs to be enhanced. The difference in the level of high-quality sustainable economic development among cities in the Central Plains urban agglomeration is the smallest, and the mean value of the Gini coefficient is about 3/5 of the overall mean value of the sample. Specifically, although the gap between individuals in Guangdong–Hong Kong–Macao and Beijing–Tianjin–Hebei with higher levels of high-quality sustainable economic development has widened, the rate is much smaller than that of the Central Plains, Chengdu–Chongqing and Guanzhong urban agglomerations with lower levels of development. It is precisely because the high-quality sustainable development of Guanzhong lags behind the continuous expansion of the gap between individuals in the urban agglomeration that the overall gap between individuals in the urban agglomeration is expanding year by year.

Table 2. Gini coefficient of high-quality, sustainable economic development level within urban agglomerations.

Time	Total	Middle Yangtze River	Harbin–Chang-chun	Central Plains	Chengdu–Chong-qing	Yangtze River Delta	Guan-zhong	Beijing–Tianjin–Hebei	South and Central Liaoning	Guangdo-ng–Hong Kong–Macao	West Side of the Strait
2004	0.0219	0.1183	0.1647	0.1001	0.1313	0.2301	0.1401	0.2985	0.2009	0.2544	0.1784
2005	0.0214	0.1178	0.1702	0.1004	0.1300	0.2223	0.2310	0.2900	0.2042	0.1997	0.1730
2006	0.0206	0.1156	0.1788	0.0932	0.1407	0.1965	0.1503	0.3134	0.1949	0.2148	0.1843
2007	0.0238	0.1625	0.1825	0.1127	0.1516	0.2151	0.3403	0.3229	0.1882	0.2234	0.1891
2008	0.0207	0.1287	0.1765	0.1121	0.1697	0.1935	0.1009	0.3123	0.1731	0.2428	0.1760
2009	0.0210	0.1180	0.1209	0.1102	0.1818	0.2119	0.1107	0.2919	0.1550	0.2122	0.1595
2010	0.0229	0.1314	0.1391	0.1104	0.2008	0.2207	0.1289	0.3165	0.1638	0.2728	0.1720
2011	0.0240	0.1436	0.1439	0.1106	0.1992	0.2328	0.1354	0.3338	0.1704	0.2809	0.1709
2012	0.0247	0.1286	0.1558	0.1171	0.2068	0.2324	0.1209	0.3350	0.1665	0.2641	0.2333
2013	0.0240	0.1303	0.1513	0.1452	0.2152	0.2278	0.1380	0.3438	0.1515	0.2800	0.1794
2014	0.0218	0.1321	0.1392	0.1211	0.2139	0.2015	0.1275	0.3330	0.1557	0.2510	0.1581
2015	0.0224	0.1373	0.1414	0.1264	0.2069	0.2039	0.1419	0.3291	0.1344	0.2677	0.1668
2016	0.0223	0.1300	0.1392	0.1321	0.2068	0.2032	0.1635	0.3283	0.1440	0.2819	0.1687
2017	0.0239	0.1701	0.1135	0.1357	0.1962	0.2106	0.1712	0.2884	0.1877	0.2705	0.1781
2018	0.0238	0.1442	0.1371	0.1615	0.2194	0.2132	0.1431	0.3046	0.1692	0.2927	0.1870
2019	0.0233	0.1455	0.1226	0.1375	0.1986	0.2158	0.1519	0.3081	0.1699	0.2808	0.1719
Mean Value	0.0226 / 0.1879	0.1346	0.1485	0.1204	0.1856	0.2145	0.1560	0.3156	0.1706	0.2556	0.1779
Growth Rate	0.64%	2.48%	−1.11%	2.75%	2.99%	−0.21%	8.93%	0.36%	−0.62%	1.30%	0.51%

3.2.2. Analysis of the Gap in High-Quality Sustainable Economic Development within Urban Agglomerations

Using the Dagum Gini coefficient, the differences between the ten major urban agglomerations are measured, and the measurement results are depicted as shown in Figure 5. From the analysis of the inter-group gap level of high-quality sustainable economic development, the following two points are obtained. First, during the investigation period, the gap between the urban agglomerations and the high-quality sustainable economic development of Guangdong, Hong Kong, and Macao is the largest, and the most prominent gap is between Guanzhong and Guangdong, Hong Kong, and Macao urban agglomerations. The average Gini coefficient between the groups reached 0.5589, close to 2 times the Gini coefficient between the sample groups. Second, the gap between urban agglomerations in the same geographical plate is small. For example, the gaps between the middle reaches of the Yangtze River and the Central Plains urban agglomeration; Hachang and the central and southern Liaoning urban agglomeration; and Guanzhong and Chengdu–Chongqing urban agglomeration are small, and the gap between the middle reaches of the Yangtze River and the Central Plains urban agglomeration is the smallest. The mean Gini coefficient between groups was only 0.1461. From the analysis of the changing trend of the high-quality sustainable economic development gap between urban agglomerations, it can be seen that the gap between the groups is slowly expanding, with a growth rate of 0.31%. Specifically, there are the following characteristics. First, the gap between Harbin–Changchun, Central Plains, central and southern Liaoning, Guangdong–Hong Kong–Macao, and other urban agglomerations shows a fluctuating narrowing trend, with an average annual reduction rate of 0.07%, 0.53%, 0.14%, and 0.05%, respectively. Second, the gap between the middle reaches of the Yangtze River, Chengdu–Chongqing, the Yangtze River Delta, Guanzhong, Beijing–Tianjin–Hebei, and other urban agglomerations is widening year by year, with an average annual growth rate of 0.43%, 0.64%, 0.90%, 1.35%, and 0.54%. The gap between Guanzhong and other urban agglomerations has the highest expansion rate among them. Third, the Central Plains with a lower level of development is expanding its distance from Guanzhong at a faster rate of development, and the average annual growth rate of inter-group differences has reached 7.19%. It can be seen that although the geographical distance between the Central Plains and the Guanzhong urban agglomeration is relatively close, there may be a severe separation in the future.

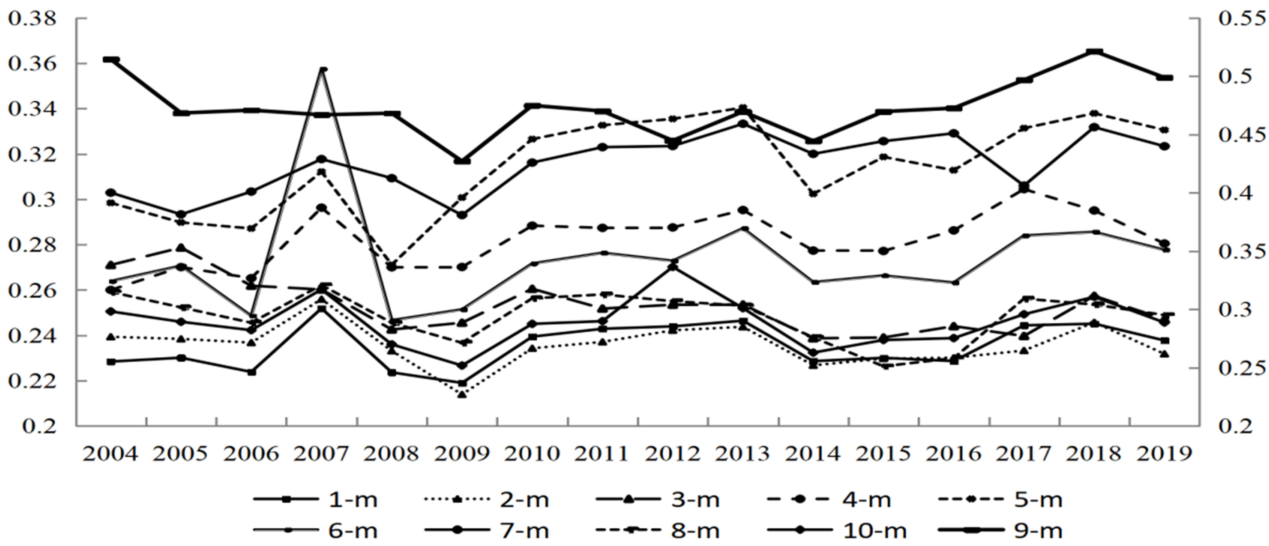


Figure 5. The evolution trend of the Gini coefficient between groups for the high-quality sustainable economic development of urban agglomerations. The numbers 1–10 refer to the urban agglomerations in the middle reaches of the Yangtze River, Harbin–Changchun, Central Plains, Chengdu–Chongqing, Yangtze River Delta, Guanzhong, Beijing–Tianjin–Hebei, central and southern Liaoning, Guangdong–Hong Kong–Macao, and the west coast of the Taiwan Strait. Figure 5 is drawn according to the Gini coefficient of economic development quality among the top ten urban agglomerations; m represents the other urban agglomerations except for the local urban agglomeration. 9-m is marked on the right longitudinal coordinate axis.

3.2.3. Source of the Gap in the High-Quality Sustainable Economic Development of Urban Agglomerations

Figure 6 shows the source of the spatial gap of high-quality sustainable economic development in urban agglomerations, and calculates and decomposes the Gini coefficient. From the analysis of the changing trend of the high-quality sustainable development of the overall economy of the urban agglomeration, the overall gap before the 18th National Congress showed a trend of "first decline and then rise", and after the 18th National Congress, it showed a trend of "first decline, then rise and then decline". It can be seen that the spatial gap of the overall economic high-quality sustainable development of the urban agglomeration fluctuates with time, but it has increased compared with the beginning of the period, and the spatial gap has an expanding trend. After analyzing the contribution rates of intra-group and inter-group differences, it was found that 70.51% of the overall gap in high-quality sustainable economic development of urban agglomerations is due to the inter-group gap. In comparison, 7.99% is due to the intra-group gap. It can be seen that the gap in high-quality sustainable economic development among urban agglomerations is still the most important factor hindering the high-quality sustainable development of the overall economy of urban agglomerations. From the analysis of the influence trend of cross-overlap between urban agglomerations, the average annual contribution rate of hypervariable density to the overall economic development quality difference of urban agglomerations is 21.50%, and the overall performance is the growth trend of "W" fluctuation.

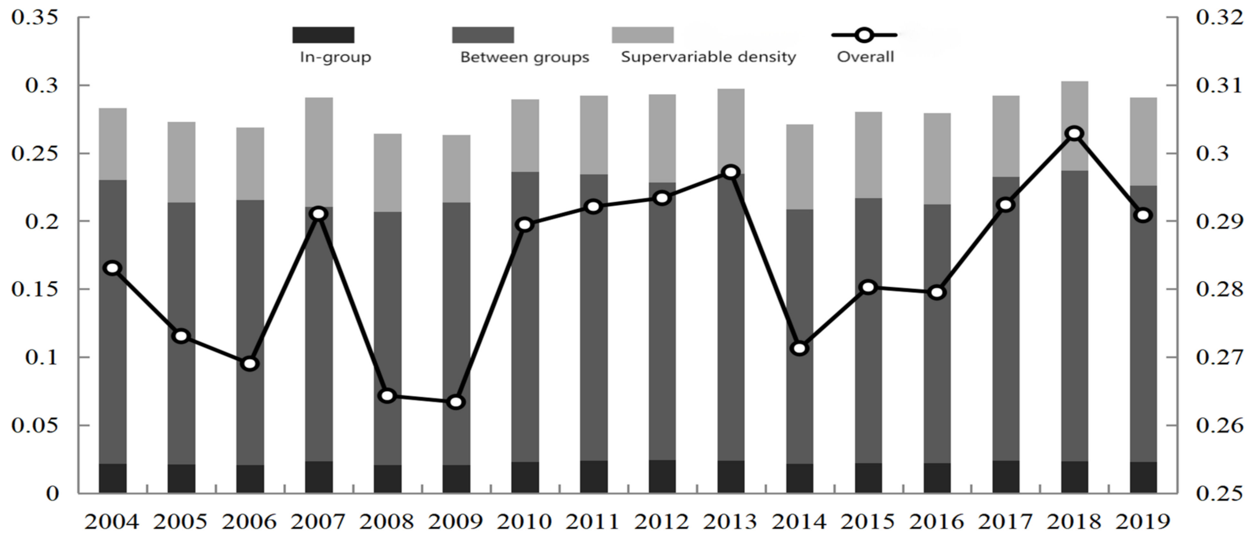


Figure 6. The total Gini coefficient and its decomposition of the high-quality sustainable economic development of urban agglomeration. The line chart is marked by the right longitudinal coordinate axis.

3.3. Indexes System and Data Sources

Figure 7 shows the dynamic distribution characteristics of high-quality sustainable economic development in the ten major urban agglomerations and within each urban agglomeration using kernel density estimation. First, the slight right shift of the overall distribution curve of the urban agglomeration indicates that the level of high-quality sustainable economic development is on the rise, while the distribution pattern shows a slight increase in width. It shows an upward pressure on the high-quality sustainable development gap of the overall economy, which is consistent with the conclusion of the Gini coefficient analysis. In addition, the right tail of the nuclear density map shows that the high-quality sustainable development of the overall economy of the urban agglomeration is converging. The gap between the individual and the average value of the high-quality sustainable economic development level is narrowing, and there is no polarization in China's urban agglomerations. Second, there are some differences in the dynamic evolution characteristics of high-quality sustainable economic development in urban agglomerations. In terms of a dynamic upward trend, except for Guangdong, Hong Kong, and Macao, other urban agglomerations' high-quality sustainable economic development levels have an upward trend. Except for Guangdong, Hong Kong, and Macao, central and southern Liaoning, and the Yangtze River Delta, the rest of the urban agglomerations have a right tail, that is, a dynamic convergence trend. The gap between the high-level individuals in the group and the average level is narrowed, which proves the robustness of the Gini coefficient on the measurement results of the intra-group gap. In addition, the distribution pattern of the nuclear density map shows that the main peak height of the distribution curve of low-level urban agglomerations with high-quality sustainable economic development, such as Harbin–Changchun, Central Plains, Chengdu–Chongqing, Guanzhong, and the west side of the Strait, has decreased, and the width has increased, indicating that the absolute gap in the high-quality sustainable development level of its internal economy is expanding year by year. At the same time, the peak and number of distribution curves show that there are obvious multi-polarization characteristics in the Guangdong–Hong Kong–Macao urban agglomeration, and the side peaks of the Yangtze River Delta and the central and southern Liaoning urban agglomeration are also increasing, indicating that there is a multi-polarization development trend, and dynamic convergence is facing greater pressure.

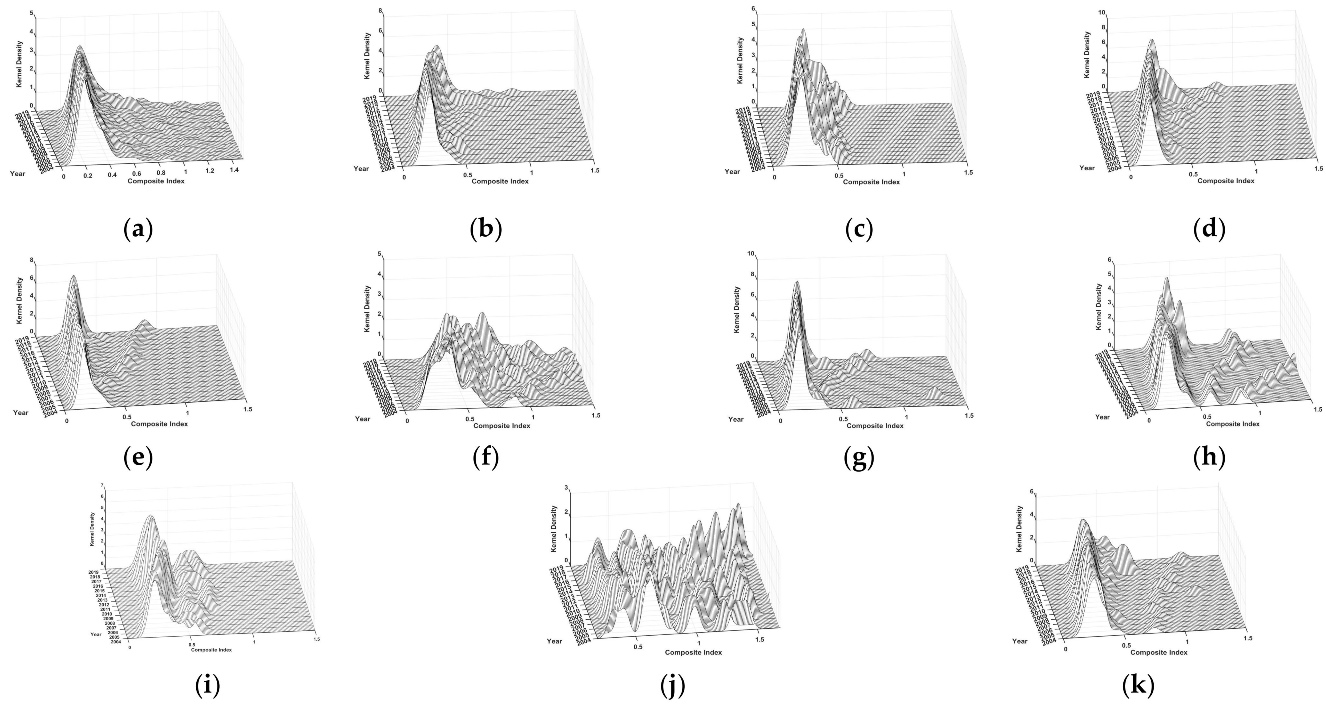


Figure 7. The dynamic evolution trend of the high-quality sustainable economic development of urban agglomerations. (**a**) is the dynamic evolution trend of all urban agglomerations. (**b**) is the dynamic evolution trend of urban agglomeration in the middle reaches of the Yangtze River. (**c**) is the dynamic evolution trend of the Harbin–Changchun urban agglomeration. (**d**) is the dynamic evolution trend of the Central Plains urban agglomeration. (**e**) is the dynamic evolution trend of the Chengdu–Chongqing urban agglomeration. (**f**) is the dynamic evolution trend of the Yangtze River Delta urban agglomeration. (**g**) is the dynamic evolution trend of the Guanzhong urban agglomeration. (**h**) is the dynamic evolution trend of the Beijing–Tianjin–Hebei urban agglomeration. (**i**) is the dynamic evolution trend of the Liaozhongnan urban agglomeration. (**j**) is the dynamic evolution trend of the Guangdong–Hong Kong–Macao urban agglomeration. (**k**) is the dynamic evolution trend of the west side of the Strait urban agglomeration.

4. Analysis of Dynamic Convergence Characteristics of High-Quality Sustainable Economic Development of Urban Agglomerations

This paper analyzes the level, time trend, spatial gap, and dynamic evolution characteristics of the high-quality sustainable economic development index of each urban agglomeration, and presents the absolute gap of the high-quality sustainable economic development of urban agglomerations. The analysis results show that the gap in high-quality sustainable economic development among individuals in some urban agglomerations is expanding, and the spatial gap mainly comes from the gap between groups. It can be seen that the gap within and between urban agglomerations is still an important factor hindering the high-quality sustainable development of the overall economy of the region. However, due to the limitations of regional resource endowments, location conditions, and development foundations, the high-quality sustainable development level of the overall economy of urban agglomerations is challenging to be consistent. Can we narrow the relative gap between urban agglomerations' high-quality sustainable economic development and make the overall high-quality sustainable economic development level of urban agglomerations dynamically coordinated? To answer this question, analyzing the convergence trend of high-quality sustainable economic development of urban agglomerations is necessary. Here, we first determine whether there is absolute β convergence in each urban agglomeration's high-quality sustainable economic development level, and verify whether there is a dynamic coordination trend among individuals in each urban agglomeration. Secondly, control variables are included to determine whether there is still a β convergence trend in urban agglomerations under the constraints of other factors. At the same time, we identify the main factors affecting the dynamic coordination of the high-quality sustainable development level of the overall regional economy. Finally, according to the characteristics of each urban agglomeration, this paper analyzes whether there is club convergence in the high-quality sustainable economic development level of urban agglomerations at the same level. It explores the dynamic coordination pattern and influencing factors among urban agglomerations.

4.1. Analysis of Dynamic Convergence Characteristics of High-Quality Sustainable Economic Development among Individuals within Urban Agglomerations

4.1.1. Absolute β Convergence Analysis

Before analyzing the β-convergence trend of each urban agglomeration, Wald, LR, L.M., and Hausman tests are performed on each sample data to optimize the model. The results show that only the Beijing–Tianjin–Hebei urban agglomeration passes all the tests, and the SDM model is selected. The rest of the urban agglomeration samples are suitable for OLS estimation. Table 3 shows that the growth rate of high-quality sustainable economic development of each urban agglomeration is significantly negatively correlated with its initial level. That is, there is an absolute β-convergence trend. The low-level individuals in the group are forming a dynamic coordination relationship with the high-level individuals with a higher growth rate. From the analysis of convergence speed, the highest absolute β convergence speed is Guanzhong urban agglomeration, followed by Zhongyuan urban agglomeration. Although the absolute gap between individuals in the Guanzhong and Zhongyuan urban agglomerations is widening, the relative gap is shrinking due to the increase in the growth rate of low-quality individuals. However, the absolute β convergence rate of Guangdong, Hong Kong, Macao, and Beijing–Tianjin–Hebei with higher quality is lower, and the quality of low-level individual development in the group needs to be improved urgently. The low convergence level of Beijing–Tianjin–Hebei can be partly explained by the spatial correlation of high-quality sustainable economic development among individuals in the group. Due to the flow of many factors to Beijing and Tianjin, the high-quality sustainable economic development of cities in Hebei has been inhibited, making it difficult to narrow the gap between the growth rate of low-quality individuals and high-quality individuals within the group. In summary, there is an absolute β convergence trend between the high-quality sustainable economic development of urban agglomerations. Guanzhong and Zhongyuan urban agglomerations with the lowest level of high-quality sustainable economic development have the fastest convergence speed. In contrast, Guangdong–Hong Kong–Macao and Beijing–Tianjin–Hebei urban agglomerations with higher quality have a slower convergence speed.

4.1.2. Conditional β Convergence Analysis

Before conducting conditional β-convergence analysis, it is necessary to screen out relevant factors that impact high-quality sustainable economic development and include them in control variables for re-analysis. Following the literature, the following control variables are included for re-estimation, and the results are shown in Table 4.

1. Degree of government intervention (*Govern*).

Government-led development will bring high-speed growth and low-quality development, but market-led development will optimize the industrial system and promote high-quality sustainable economic development [36]. However, some scholars have found that government intervention will promote high-quality sustainable economic development by improving enterprises' innovation environment and innovation ability [37]. Although the current research conclusions on the impact of government intervention on high-quality sustainable economic development are inconsistent, they all prove that government intervention will significantly affect high-quality sustainable economic development. It is necessary to discuss the role of government intervention in the convergence characteristics of high-quality sustainable economic development of urban agglomerations. Here, the proportion of fiscal expenditure and GDP is used to measure the degree of government intervention.

2. Financial development level (*Finance*).

Financial development can improve the external financing environment of enterprises, reduce the transaction costs of enterprises, improve the efficiency of enterprises to obtain financial resources, optimize capital allocation, and promote high-quality sustainable economic development. The structural contradiction in financial development is an important factor restricting the high-quality sustainable development of the economy. Promoting financial development, serving the real economy, and continuously optimizing the financial structure, improving the financial market and product system will enhance the efficiency of resource allocation and promote high-quality sustainable economic development by improving financing facilitation and reducing the cost of the real economy [38]. Therefore, it is necessary to explore the impact of the financial development level on the convergence of the high-quality sustainable economic development of urban agglomerations. Here, the ratio of the balance of deposits and loans of local financial institutions to regional GDP is used to represent the level of financial development.

3. Urbanization level (*Urban*).

Network externalities accompany urbanization development. Urbanization can achieve economies of scale and promote high-quality sustainable economic development by improving resource-matching efficiency, reducing transaction costs, strengthening knowledge diffusion and spillover, and promoting industrial divisions [39]. However, urbanization is also accompanied by the continuous expansion of urban scale, resulting in urban sprawl, increasing the cost of urban governance, while causing other problems such as environmental pollution and hindering high-quality sustainable economic development [40]. Here, the ratio of the population of the regional cities at the end of the year to the total population is used to measure urbanization level.

4. Human capital level (*Human*).

Human capital continuously improves production efficiency, promotes technological progress, and promotes high-quality sustainable economic development through knowledge absorption, learning and imitation, and the accumulation of experience. However, there are certain basic conditions for human capital's positive role. Therefore, research has shown that human capital has a non-linear impact on high-quality sustainable economic development, and because of the inconsistency of regional technical, economic, and institutional resource conditions, it will cause differences in the matching degree of human capital with regions, industrial structures, and departments, which will have a heterogeneous impact on high-quality sustainable economic development [41]. Therefore, human capital should be introduced when analyzing the convergence characteristics of high-quality sustainable economic development of urban agglomerations. Here, the level of human capital is represented by the number of students in institutions of higher learning per 10,000 people.

The above variables are introduced to analyze the conditional β convergence state of each urban agglomeration. Before the estimation, the model is still optimized by LR, Wald, LM, and other tests. The results show that Beijing–Tianjin–Hebei and Guangdong–Hong Kong–Macao are suitable for the SDM and SAR models, respectively, and the rest are suitable for OLS estimation. The results are shown in Table 4.

Table 3. Absolute β convergence of the economic high-quality sustainable development level of urban agglomerations.

Region Model	(1) Nt-OLS	(2) Nt-OLS	(3) Nt-OLS	(4) Nt-OLS	(5) Nt-OLS	(6) Nt-OLS	(7) N-SDM	(8) N-OLS	(9) N-OLS	(10) Nt-OLS
β	−0.622 *** (−13.98)	−0.230 *** (−4.354)	−0.732 *** (−10.890)	−0.319 *** (−7.656)	−0.580 *** (−12.824)	−0.940 *** (−12.487)	−0.303 *** (−4.844)	−0.280 *** (−5.532)	−0.235 *** (−3.645)	−0.628 *** (−12.077)
θ							0.307 *** (4.721)			
λ							0.494 *** (5.515)			
R^2	0.318	0.113	0.379	0.197	0.289	0.487	0.292	0.186	0.090	0.328
LM_{lag}	0.05 [0.823]	6.958 *** [0.008]	7.235 *** [0.007]	3.291 * [0.070]	0.009 [0.925]	3.717 * [0.054]	35.400 *** [0.000]	9.910 *** [0.002]	7.061 *** [0.008]	0.474 [0.491]
RLM_{lag}	0.084 [0.772]	0.229 [0.632]	0.001 [0.975]	0.051 [0.822]	0.000 [0.998]	0.236 [0.627]	14.975 *** [0.000]	15.496 *** [0.000]	21.821 *** [0.000]	11.465 *** [0.001]
LM_{err}	0.015 [0.902]	6.765 *** [0.009]	7.722 *** [0.005]	3.432 * [0.064]	0.009 [0.923]	5.528 ** [0.019]	38.213 *** [0.000]	26.049 *** [0.000]	18.505 *** [0.000]	0.426 [0.514]
RLM_{err}	0.084 [0.772]	0.037 [0.847]	0.488 [0.485]	0.192 [0.661]	0.001 [0.980]	2.047 [0.152]	17.789 *** [0.000]	31.636 *** [0.000]	33.265 *** [0.000]	11.417 *** [0.001]
LR_{lag}		0.126 [0.723]	2.113 [0.146]	0.868 [0.352]		3.417 * [0.065]	3.458 * [0.063]	0.433 [0.510]	0.929 [0.335]	
Wald-lag		0.075 [0.784]	0.424 [0.515]	0.374 [0.541]		1.992 [0.158]	4.268 ** [0.039]	0.760 [0.383]	0.513 [0.474]	
LR_{err}		−0.187 [1.000]	−0.319 [1.000]	0.207 [0.649]		−0.653 [1.000]	6.195 ** [0.013]	0.473 [0.492]	−0.344 [1.000]	
Wald-err		0.001 [0.974]	0.019 [0.892]	0.247 [0.619]		0.619 [0.432]	5.929 ** [0.015]	1.599 [0.206]	0.094 [0.760]	

Note: *, **, *** are significant at the levels of 10%, 5%, and 1%, respectively; ( ) is t value; [ ] is p value. Both individual and time-fixed effects were tested, but due to space constraints, the table is not listed. N represents the existence of an individual fixed effect, and t represents the existence of a time fixed-effect. The names of urban agglomerations represented by (1)–(10) are the same as those in Figure 5.

First, regardless of whether other factors are considered, there is a β-convergence trend between the high-quality sustainable economic development of each urban agglomeration, indicating that low-quality individuals in each urban agglomeration are achieving dynamic coordination with high-quality individuals at a higher growth rate. Second, the Guanzhong urban agglomeration with the lowest high-quality sustainable economic development level has the fastest convergence speed. Thirdly, the spatial correlation of high-quality sustainable economic development among individuals in Beijing–Tianjin–Hebei and Guangdong–Hong Kong–Macao is an important obstacle to conditional β convergence, and also an important factor leading to the low convergence speed of Beijing–Tianjin–Hebei and Guangdong–Hong Kong–Macao. Compared with the absolute β convergence speed, the conditional β convergence speed of central and southern Liaoning and the western coast of the Strait has been greatly improved. It can be seen that the relevant basic conditions are still the key to restricting the growth rate of low-quality individuals in the interior. Fourth, other factors have heterogeneous effects on urban agglomerations' high-quality sustainable economic development rate. Government intervention will hinder the high-quality sustainable economic development of the Central Plains and the urban agglomerations on the west side of the Strait, but it will promote the high-quality sustainable economic development of the Beijing–Tianjin–Hebei region. It can be seen that government intervention is an important factor that causes the widening gap in the high-quality sustainable economic development of the Beijing–Tianjin–Hebei region. Financial development is conducive to promoting the high-quality sustainable development of the economy on the west side of the Strait. It will also promote narrowing the gap between the Central Plains, the Yangtze River Delta, Guanzhong, and the Beijing–Tianjin–Hebei region. Urbanization has a limited effect on the high-quality sustainable economic development of urban agglomerations and can only significantly promote the high-quality sustainable economic development of urban agglomerations in central and southern Liaoning. It can be seen that the difference in urbanization is still an important factor causing the gap between individuals in central and southern Liaoning. Human capital can only significantly promote the high-quality sustainable economic development of the central and southern Liaoning and Guangdong–Hong Kong–Macao urban agglomerations. Still, it has an insignificant effect on other urban agglomerations. However, it also shows that narrowing the differences in human capital among individuals in the central and southern Liaoning and Guangdong–Hong Kong–Macao will help promote the dynamic and coordinated development of the central and southern Liaoning and Guangdong–Hong Kong–Macao urban agglomerations.

4.2. Analysis of Dynamic Convergence Characteristics of High-Quality Sustainable Economic Development among Urban Agglomerations

To analyze whether the high-quality sustainable economic development among urban agglomerations tends to be dynamically coordinated, the absolute β and conditional β convergence trends of urban agglomerations and different levels of urban agglomerations are estimated. After testing, the SDM model applies to the national overall and second-level urban agglomerations, the SAR model applies to the first level, and the ordinary panel model applies to the third level. The specific results are shown in Table 5.

The estimation results show that there are both absolute β convergence trends and conditional β convergence trends in the urban agglomeration, and spatial correlation is still the key factor for two convergence trends. It can be seen that the high-quality sustainable economic development level among the ten major urban agglomerations is moving towards dynamic coordination, and expanding the spatial spillover effect among urban agglomerations in the future is still an important way to promote the high-quality sustainable development of the overall economy.

There are also absolute β convergence and conditional β convergence trends in urban agglomerations at different levels, but the convergence rate shows the gradient characteristics of "third level > second level > first level". It can be seen that the dynamic convergence speed of the high-quality development level among the third-level urban agglomerations with a low high-quality economic development level is faster, and it is easier to realize the dynamic coordination relationship among urban agglomerations. Government intervention, financial development, and urbanization have heterogeneous effects on urban agglomerations' high-quality sustainable economic development at different levels. Government intervention and financial development significantly impact the overall high-quality sustainable economic development of urban agglomerations. Suppose government intervention or financial development is enhanced. In that case, it will help to narrow the relative gap of high-quality sustainable economic development among urban agglomerations and promote the convergence of high-quality sustainable economic development of urban agglomerations. Only financial development significantly impacts the high-quality sustainable economic development of the first- and second-tier urban agglomerations. It can be seen that the first and second-level urban agglomerations need to promote financial development, coordinate the capital allocation gap, optimize the overall capital allocation efficiency, and then promote the dynamic coordination of high-quality sustainable economic development among urban agglomerations. Both financial development and urbanization will significantly affect the high-quality sustainable economic development level of the third-level urban agglomeration, which shows that compared with other levels of urban agglomerations, the difference in urbanization within the third-level urban agglomeration is still an important reason for the widening gap in high-quality sustainable economic development.

After analyzing the content of the dynamic convergence part of high-quality sustainable economic development among urban agglomerations, this study aggregates all the main analysis conclusions to present the main research conclusions of this part more clearly. The results are shown in Table 6. Based on the above analysis results, we divide the convergence level of high-quality sustainable development of the urban agglomeration economy into three levels: high, medium, and low.

Table 4. Conditional β convergence estimation results for the high-quality sustainable economic development of urban agglomerations.

Region Model	(1) Nt-OLS	(2) Nt-OLS	(3) Nt-OLS	(4) Nt-OLS	(5) Nt-OLS	(6) Nt-OLS	(7) N-SDM	(8) N-OLS	(7) N-SAR	(10) Nt-OLS
β	−0.565 *** (−12.339)	−0.223 *** (−4.159)	−0.693 *** (−9.993)	−0.337 *** (−7.356)	−0.483 *** (−9.382)	−0.782 *** (−8.626)	−0.340 *** (−5.156)	−0.304 *** (−4.054)	−0.331 *** (−4.060)	−0.692 *** (−11.985)
Govern	−0.028 (−1.474)	−0.005 (−0.899)	−0.009 * (−1.949)	−0.002 (−0.244)	−0.011 (−0.847)	−0.004 (−0.282)	0.037 * (1.935)	−0.008 (−0.220)	0.140 (1.282)	−0.103 * (−1.666)
Finance	0.135 (0.695)	−0.008 (−0.109)	−0.040 *** (−2.854)	−0.173 (−1.612)	−0.148 * (−1.870)	−0.087 * (−1.907)	−0.340 ** (−2.845)	−0.131 (−0.858)	−0.637 (−1.061)	0.033 * (1.858)
Urban	0.002 (0.202)	−0.007 (−0.238)	0.010 (0.684)	0.014 (1.587)	−0.002 (−0.309)	0.030 (0.632)	−0.011 (−0.853)	0.029 * (1.695)	0.024 (0.620)	−0.003 ** (−2.567)
Human	−0.067 (−1.220)	−0.035 (−0.275)	0.070 (0.962)	−0.037 (−0.447)	−0.062 (−1.050)	0.021 (−0.0477)	−0.031 (−0.303)	0.480 * (1.800)	0.207 ** (2.057)	−0.003 (−0.384)
θ							0.234 ** (2.259)			
$W\times$ control variable							Yes			
Λ							0.287 ** (2.398)		0.282 ** (2.462)	
R^2	0.347	0.131	0.433	0.228	0.316	0.527	0.382	0.261	0.202	0.353
LM_{lag}	0.001 [0.986]	6.711 ** [0.010]	7.500 *** [0.006]	3.482 * [0.062]	0.048 [0.827]	2.881 * [0.090]	18.765 *** [0.000]	12.583 *** [0.000]	5.164 ** [0.023]	0.353 [0.552]
RLM_{lag}	0.717 [0.397]	0.093 [0.760]	0.480 [0.489]	0.029 [0.864]	0.012 [0.913]	0.267 [0.606]	6.997 *** [0.008]	6.179 ** [0.013]	3.463 * [0.063]	4.566 ** [0.033]
LM_{err}	0.123 [0.726]	6.618 ** [0.010]	9.067 *** [0.003]	3.465 * [0.063]	0.039 [0.844]	5.114 ** [0.024]	13.143 *** [0.000]	22.559 *** [0.000]	7.236 *** [0.007]	0.012 [0.913]
RLM_{err}	0.839 [0.360]	0.001 [0.987]	2.047 [0.153]	0.012 [0.912]	0.003 [0.957]	2.499 [0.114]	3.364 * [0.067]	16.154 *** [0.000]	2.923 * [0.087]	4.225 ** [0.040]
LR_{lag}		9.208 [0.101]	12.128 ** [0.033]	5.878 [0.318]		4.952 [0.422]	24.685 *** [0.000]	5.049 [0.410]	10.403 * [0.065]	
Wald-lag		0.075 [0.784]	0.424 [0.515]	0.374 [0.541]		1.992 [0.158]	4.268 ** [0.039]	0.760 [0.383]	0.513 [0.474]	
LR_{err}		7.885 [0.163]	6.496 [0.261]	5.413 [0.368]		0.446 [0.994]	27.806 *** [0.000]	3.675 [0.597]	8.372 [0.137]	
Wald-err		0.001 [0.974]	0.019 [0.892]	0.247 [0.619]		0.619 [0.432]	5.929 ** [0.015]	1.599 [0.206]	0.094 [0.760]	

Note: *, **, *** are significant at the levels of 10%, 5%, and 1%, respectively.

Table 5. Convergence estimation results of high-quality sustainable economic development of urban agglomerations at all levels.

Region	Total		First Level		Second Level		Third Level	
Type	Absolute	Conditional	Absolute	Conditional	Absolute	Conditional	Absolute	Conditional
Model	Nt-SDM	Nt-SDM	Nt-SAR	Nt-SAR	Nt-SDM	Nt-SDM	Nt-OLS	Nt-OLS
β	−0.613 *** (−30.545)	−0.561 *** (−27.443)	−0.525 *** (−14.930)	−0.489 *** (−13.347)	−0.553 *** (−19.133)	−0.498 *** (−16.823)	−0.696 *** (−18.648)	−0.621 *** (−15.661)
Govern		−0.007 *** (−2.708)		0.004 (0.268)		−0.013 *** (−4.252)		−0.002 (−0.359)
Finance		−0.080 *** (−6.115)		−0.185 ** (−2.276)		−0.053 *** (−3.559)		−0.101 *** (−4.135)
Urban		−0.005 (−1.000)		−0.007 (−0.838)		0.006 (0.885)		−0.022 ** (−2.030)
Hum		0.024 (1.205)		−0.052 (−1.160)		−0.040 (−1.012)		0.034 (1.120)
θ	0.953 *** (9.356)	0.853 *** (8.358)			0.730 *** (8.550)	0.709 *** (8.083)		
$W\times$ control variable		Yes				Yes		
Λ	0.755 *** (18.762)	0.752 *** (18.397)	0.350 *** (4.604)	0.360 *** (4.774)	0.712 *** (15.913)	0.670 *** (13.518)		
R^2	0.477	0.501	0.501	0.513	0.525	0.553	0.362	0.399
LM_{lag}	30.702 *** (0.000)	34.630 *** (0.000)	5.042 ** (0.025)	5.622 ** (0.018)	40.745 *** (0.000)	39.557 *** (0.000)	2.247 (0.134)	1.325 (0.250)

Table 5. *Cont.*

Region Type Model	Total Absolute Nt-SDM	Total Conditional Nt-SDM	First Level Absolute Nt-SAR	First Level Conditional Nt-SAR	Second Level Absolute Nt-SDM	Second Level Conditional Nt-SDM	Third Level Absolute Nt-OLS	Third Level Conditional Nt-OLS
RLM_{lag}	44.325 *** (0.001)	27.085 *** (0.000)	3.848 * (0.068)	3.465 * (0.064)	42.372 *** (0.000)	24.456 *** (0.000)	2.334 (0.127)	0.271 (0.603)
LM_{err}	106.095 *** (0.000)	99.852 *** (0.000)	9.315 *** (0.002)	10.602 *** (0.001)	114.682 *** (0.000)	101.384 *** (0.000)	0.913 (0.339)	1.055 (0.304)
RLM_{err}	119.718 *** (0.000)	92.307 *** (0.000)	5.122 ** (0.024)	6.075 ** (0.014)	116.309 *** (0.000)	86.283 *** (0.000)	1.000 (0.317)	0.001 (0.974)
Wald-lag	87.541 *** (0.000)	79.745 *** (0.000)	4.238 ** (0.040)	11.244 ** (0.047)	73.100 *** (0.000)	78.805 *** (0.000)		
LR_{lag}	79.177 *** (0.000)	72.402 *** (0.000)	4.090 ** (0.043)	10.308 * (0.063)	67.675 *** (0.000)	76.446 *** (0.000)		
Wald-err	25.463 *** (0.002)	25.885 *** (0.003)	0.622 (0.430)	3.049 (0.693)	18.155 *** (0.000)	29.833 *** (0.000)		
LR_{err}	30.108 *** (0.002)	29.993 *** (0.004)	0.623 (0.430)	4.038 (0.544)	22.857 *** (0.000)	37.419 *** (0.000)		

Note: *, **, *** are significant at the levels of 10%, 5%, and 1%, respectively.

Table 6. The convergence levels of the high-quality sustainable development of urban agglomeration economies.

Convergence	**Middle Yangtze River**	**Harbin–Changchun**	**Central Plains**	**Chengdu–Chongqing**	**Yangtze River Delta**	**Guanzhong**	**Beijing–Tianjin–Hebei**		**South and Central Liaoning**	**Guangdong–Hong Kong–Macao**	**West Side of the Strait**
Absolute β	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes
Conditional β	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes
Absolute β convergence level	Middle	Low	High	Low	Middle	High	Low		Low	Low	Middle
Conditional β convergence level	High	Low	High	Low	Middle	High	Low		Low	Low	High
Club convergence	Total		First level			Second level				Third level	
		Guangdong–Hong Kong–Macao	Yangtze River Delta	Beijing–Tianjin–Hebei	Middle Yangtze River	Central Plains	Chengdu–Chongqing	South and Central Liaoning	Harbin–Changchun	Guanzhong	West Side of the Strait
Absolute β	Yes		Yes			Yes				Yes	
Conditional β	Yes		Yes			Yes				Yes	
Absolute β convergence level			Low			Middle				Hihg	
Conditional β convergence level			Low			Middle				High	

5. Conclusions and Policy Recommendations

Main Results

To comprehensively promote the high-quality, sustainable economic development of urban agglomerations, this paper uses the entropy method, Dagum Gini coefficient, and kernel density estimation method to measure and describe the spatial pattern of high-quality, sustainable economic development of ten urban agglomerations, and uses the spatial econometric model to estimate the β convergence trend within urban agglomerations and among urban agglomerations at different levels and to explore the critical factors to promote the dynamic coordination of high-quality sustainable economic development of urban agglomerations. First, urban agglomerations, in general, are experiencing high-quality sustainable economic development. However, the Guanzhong, Central Plains, and Chengdu–Chongqing urban agglomerations with low quality are developing at a faster pace. Second, the gap in the level of high-quality sustainable economic development in the Beijing–Tianjin–Hebei urban agglomeration is the largest, while the Central Plains urban agglomeration is the opposite. The gap between Guanzhong and other urban agglomerations is the largest, and the gap is expanding year by year, while the spatial gap between the middle reaches of the Yangtze River and the Central Plains urban agglomeration is the smallest. The gap between urban agglomerations is the most important reason hindering the high-quality sustainable development of the overall regional economy, with a contribution rate of 70.51%. Third, the overall economic high-quality sustainable development level of urban agglomerations is on the rise and converging, but there is upward pressure on the spatial gap. There are differences in the dynamic evolution characteristics of high-quality sustainable economic development in urban agglomerations. The Guangdong–Hong Kong–Macao urban agglomeration has multi-polarization characteristics, and the future dynamic convergence resistance is the largest. Fourth, from the analysis of the internal relationship of urban agglomerations, there is an absolute and conditional β convergence trend in each urban agglomeration. The Guanzhong urban agglomeration with the lowest level of high-quality sustainable economic development has the fastest convergence speed. In contrast, the Beijing–Tianjin–Hebei region has slow convergence due to the difference in government intervention and the crowding-out effect of the central city space. Financial development is the key to promoting the dynamic coordination between the Central Plains and Guanzhong urban agglomerations. From the analysis of the relationship between urban agglomerations, there is an absolute and conditional β convergence trend in the overall and all levels of urban agglomerations. Still, the convergence speed of each level shows the gradient characteristics of "third level > second level > first level". It is proved that the third level with a weak development foundation and a low level of high-quality sustainable economic development has a faster convergence speed. To accelerate the dynamic coordination of the high-quality sustainable economic development of the first-level and second-level urban agglomerations, it is necessary to constantly balance the differences in financial development among urban agglomerations within the hierarchy and optimize the allocation of credit resources.

In view of the above research conclusions, this study puts forward the following policy recommendations:

(1) Build a differentiated urban agglomeration collaborative linkage mechanism, exert the radiation-driving effect within and between urban agglomerations, and continuously narrow the spatial gap between urban agglomerations.
(2) Accurately implement the measures to promote high-quality economic development, accelerate the formation of a dynamic and coordinated development pattern of urban agglomerations, and promote the high-quality development of the overall economy of urban agglomerations.

In short, this study has three main contributions. Firstly, based on paying attention to the relevant factors and overall evaluation of high-quality development in the past, research on promoting high-quality development is carried out from the perspective of comparative analysis of multiple urban agglomerations, which helps to give full play to the dominant position of urban agglomerations in the overall high-quality development of the region. Secondly, this study compares and analyzes the differences in the high-quality development status of different urban agglomerations before and after the major historical nodes in China from the two dimensions of time and space, proving the important position of the Chinese government in driving the high-quality development process of urban agglomerations, and retests the relevant theories of government intervention. Thirdly, based on the analysis of the degree of convergence of urban agglomerations, according to the characteristics of urban agglomerations, this study divides urban agglomerations into three levels, studies the status and influencing factors of club convergence of them, and explores the possibility of forming a coordinated development trend among urban agglomerations with similar characteristics.

However, there are still some limitations in this study. Firstly, we used official data available at the prefecture-level-city level, making the results highly credible. However, we did not consider the data at China's county and township levels. Therefore, the research conclusions have limited guiding significance at these levels. To improve the applicability of the research conclusions, we plan to increase the sampling coverage, expand the data capacity, and continuously enhance the quality of our research in the future. Secondly, in terms of research depth, although we have comprehensively demonstrated the spatial differences, dynamic characteristics, and convergence of high-quality sustainable development of urban agglomerations and tested and analyzed the role of relevant influencing factors, due to space limitations, we have not yet carried out an empirical test on the internal mechanism of each restricting factor affecting the high-quality, sustainable development of urban agglomerations. In the future, we will focus on empirical analyses of the mechanism of each influencing factor.

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Appendix A

Table A1. The calculation results of the high-quality sustainable economic development of urban agglomerations.

Time	Total	Middle Yangtze River	Harbin–Changchun	Central Plains	Chengdu–Chongqing	Yangtze River Delta	Guan-zhong	Beijing–Tianjin–Hebei	South and Central Liaoning	Guang-dong–Hong Kong–Macao	West Side of the Strait
2004	0.3163	0.2352	0.2497	0.1795	0.1953	0.3768	0.1962	0.3442	0.3063	0.7829	0.2968
2005	0.3206	0.2386	0.2686	0.1826	0.1959	0.3876	0.2437	0.3481	0.3080	0.7253	0.3072
2006	0.3235	0.2454	0.2785	0.1921	0.2013	0.3989	0.2173	0.3625	0.3057	0.7343	0.2995
2007	0.3647	0.2818	0.2935	0.2359	0.2148	0.4622	0.2907	0.3960	0.3402	0.8031	0.3290
2008	0.3531	0.2657	0.3028	0.2281	0.2255	0.4071	0.2209	0.4249	0.3579	0.7887	0.3095
2009	0.3575	0.2682	0.2923	0.2289	0.2323	0.4816	0.2295	0.4224	0.3702	0.7281	0.3216
2010	0.3901	0.2779	0.3097	0.2392	0.2479	0.5342	0.2372	0.4503	0.3980	0.8674	0.3393
2011	0.4072	0.2916	0.3235	0.2616	0.2631	0.5679	0.2461	0.4660	0.4129	0.8899	0.3492
2012	0.4283	0.2993	0.3457	0.2803	0.2871	0.6099	0.2627	0.4887	0.4239	0.8780	0.4076
2013	0.4557	0.3178	0.3553	0.3125	0.3000	0.6525	0.2728	0.5318	0.4424	0.9840	0.3876
2014	0.4498	0.3333	0.3519	0.3092	0.3129	0.5969	0.2885	0.5438	0.4447	0.9346	0.3823
2015	0.4743	0.3543	0.3638	0.3272	0.3260	0.6464	0.3061	0.5837	0.3845	1.0350	0.4157
2016	0.4955	0.3753	0.3810	0.3388	0.3331	0.6597	0.3354	0.6212	0.4019	1.0760	0.4331

Table A1. *Cont.*

Time	Total	Middle Yangtze River	Harbin–Changchun	Central Plains	Chengdu–Chongqing	Yangtze River Delta	Guan-zhong	Beijing–Tianjin–Hebei	South and Central Liaoning	Guang-dong–Hong Kong–Macao	West Side of the Strait
2017	0.6080	0.4880	0.4551	0.4541	0.3682	0.8562	0.3735	0.6882	0.4443	1.3988	0.5538
2018	0.5643	0.4245	0.3993	0.3898	0.3730	0.7651	0.3396	0.6804	0.4154	1.3728	0.4835
2019	0.5848	0.4542	0.4396	0.4048	0.3926	0.7983	0.3682	0.7054	0.4248	1.3509	0.5094
Mean Value	0.4308	0.3219	0.3381	0.2853	0.2793	0.5751	0.2768	0.5036	0.3863	0.9594	0.3828
Growth Rate	0.0462	0.0486	0.0406	0.0609	0.0480	0.0566	0.0513	0.0496	0.0239	0.0416	0.0408

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