

Essay

Evaluation of Supply and Demand Balance and Spatial Spillover Effect of Age-Friendly Environment

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Abstract: Given the rapid development of population aging, regions face significant challenges in providing diverse public service resources for the elderly. Constructing an age-friendly environment actively addresses population aging and ensures the well-being of the elderly. This study employed panel data from 31 provinces (municipalities) in China spanning the years 2014 to 2020. The research utilized a coupling coordination degree model, Theil index, Moran index method, and spatial econometric model to empirically examine the level of coupling coordination development, regional differences, and spatial spillover effects of age-friendly environments. The findings indicate the following: (1) In terms of coupling and coordination development, the degree of coupling and coordination of age-friendly environments in China shows a consistent upward trend over the years. The eastern region exhibits the highest level of development, surpassing the national average, while the western region has the lowest level, followed by the northeast and central regions. (2) In terms of regional development disparities, inter-regional differences gradually intensify due to variations in development status and resource endowment, playing a significant role in overall variations. Within regions, the highest intra-regional differences occur in the eastern region, while the lowest occur in the western region. (3) Considering the spatial spillover effect, the coupling coordination degree of age-friendly environments demonstrates positive spatial autocorrelation. Various development clusters and variables exert diverse influences on the coupling coordination degree of age-friendly environments within the region, while the spatial spillover effect of surrounding regions manifests distinct development patterns. The findings of this study contribute to enhancing the quality of age-friendly environment construction and promoting coordinated development among different regions.

Keywords: age-friendly environment; supply and demand coordination; coupling coordination model; spatial spillovers



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1. Introduction

Aging is not merely a physiological process, but a concept shaped by the social and historical environment [1]. According to the latest data from the Department of Aging of the National Health Commission of China in 2022, it is projected that the total number of individuals aged 60 and above will surpass 300 million during the “14th Five-Year Plan” period, representing over 20% of the population and signifying a stage of moderate aging. By approximately 2035, the elderly population aged 60 and above is expected to exceed 400 million, accounting for more than 30% of the total population, and entering a stage of severe aging [2]. The situation and characteristics of China’s aging, characterized by a large population, rapid pace, significant disparities, and substantial challenges, necessitate the enhancement of age-friendly environment construction and quality in China. During the construction of age-friendly environment, establishing and maintaining a coordinated and harmonized relationship between supply and demand can generate positive effects, enhance the output and benefits of age-friendly environment provision, and ensure the

continuous supply of high-quality age-friendly environments, thus creating a virtuous cycle. Conversely, if the supply and demand of age-friendly environment construction fail to establish a well-balanced and coordinated relationship, the lack of coordination and mismatch in terms of supply quantity, content, structure, and demand will impede the effective enhancement of output and value-added benefits in age-friendly environment construction, leading to a vicious cycle. Thus, it is of strategic importance to conduct accurate assessments of the current state of age-friendly environment construction, examine the supply-demand balance in age-friendly environment construction across different regions, elucidate the factors influencing the construction of age-friendly environments and their spatial spillover effects, and foster the coordinated development of the supply-demand relationship in age-friendly environment construction.

Theoretical research on aging has evolved from the concept of “successful aging” to “healthy aging,” and further to “active aging” [3]. Active aging emphasizes the provision of optimal opportunities for older individuals to maintain their health, engage in meaningful activities, and ensure their security in old age. Drawing upon the principles of active aging, the World Health Organization (WHO) introduced the concept of “age-friendly city” in 2000, which encourages a positive perception of old age through the provision of supportive services, environments, and facilities, addressing the challenges associated with population aging. In response, China has progressively integrated the development of livable environments for older adults into its national planning. Therefore, in the current era characterized by rapid population aging and a growing aspiration for improved quality of life, the construction of age-friendly environments holds significant importance in addressing the challenges of population aging and fostering active aging [4].

In recent years, scholars have focused on researching elderly-friendly cities and communities, with particular emphasis on evaluation methods and construction approaches. Regarding evaluation methods, some scholars extract evaluation indicators through interviews and theoretical analysis. Jelokhani-Niaraki et al. employ multi-criteria decision analysis and public participation GIS to assess the age-friendliness of cities by integrating the weight criteria determined by the elderly with information collected from ordinary citizens [5]. Lak et al. identified key influencing factors through grounded theory and semi-structured interviews to determine the needs and preferences of elderly individuals regarding public open spaces. Subsequently, the suitability of age-friendly public spaces is assessed through data analysis and model development [6]. Additionally, many scholars utilize statistical analysis to establish an index system for assessing the level of construction. As an example, Bhuyan et al. conducted a qualitative analysis of data from older Singaporeans and key informants in elder-care communities. Based on this analysis, they proposed a framework for developing elder-care environments that address inclusion, social environment, physical environment, sense of place, and safety [7]. Taking the perspective of older individuals, Morowatisharifabad et al. utilized questionnaire survey data and conducted SPSS analysis and *T*-tests to establish an index system for age-friendly cities, covering social, communication, culture, entertainment, and healthcare aspects [8]. Xu Jixiang et al. conducted a large-scale survey and exploratory factor analysis to evaluate the construction of age-friendly communities across five dimensions: housing, transportation, community environment, social participation, and community and health services [9].

Regarding construction approaches, the focus of age-friendly cities and communities has shifted towards meeting the specific and specialized needs of older populations. This development mode emphasizes the importance of allocating age-friendly environments to meet these requirements [10]. In terms of research on construction path strategies, Sun Zhongjun et al. began by examining the development process of the theory of active aging. They identify the elderly care needs that arise during the aging process and propose construction strategies for creating a friendly environment across three dimensions: policy, personal living environment, and social and cultural environment [11]. Zhang et al. developed an evolutionary game model involving local governments, investors, and residents as construction stakeholders. This model presents a novel approach to enhancing the age-

friendly environment through collaborative value co-creation among multiple entities [12]. Building upon the theoretical framework of community capacity building, Zhang Jia'an put forth a construction strategy that emphasizes the active promotion of elderly participation and advocates for multi-subject and cross-departmental cooperation [13]. Regarding specific measures along the construction path, Gaglione et al. utilized fuzzy technology to assess the safety and urban attributes of pedestrian networks and built environments. They suggested the classification of communities into regions based on favorable characteristics, thus enhancing elderly individuals' access to urban services [14]. Purnomo et al. employed qualitative methods including observation, in-depth interviews, and literature research, and presented strategies to improve the understanding of government and social deficiencies in construction. They underscored the importance of coordinated and collaborative efforts among multiple stakeholders, along with the implementation of pertinent laws and policies, to elevate Surabaya's age-friendly city status [15].

In summary, currently, domestic and foreign scholars primarily concentrate on evaluating and strategically researching the supply of age-friendly environments in specific cities or regions. However, there is a lack of studies examining the sources of regional development differences and the spatial correlation between the supply and demand for age-friendly environments. This research takes all 31 provinces in China as the research subject and employs the coupling coordination degree model and Theil Index to measure the level of coordination between the supply and demand of age-friendly environments. The aim is to objectively illustrate the trend of coordinated development and regional differences in age-friendly environment construction in each province. Additionally, the Moran's I Index is used to verify spatial correlation. The paper explores the spatial spillover effect of influencing factors using the spatial Durbin model with double fixed effects. Finally, it proposes countermeasures and suggestions to achieve supply and demand equilibrium in age-friendly environment construction across provinces and reduce interprovincial disparities.

2. Research Methods and Data Sources

2.1. Supply-Demand Coupling Coordination Model of Age-Friendly Environment

There exists an inherent "symbiotic relationship" between the supply and demand in the construction process of an age-friendly environment, wherein they mutually complement and influence each other. To gain a comprehensive understanding of the actual state of coordinated development between the two subsystems, the coupling coordination degree model is employed to assess the level of coordination and dynamic trends between supply and demand. The calculation formula is as follows:

$$X_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(X_{ij}) - \min(x_{ij})} \quad (1)$$

$$X_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(X_{ij}) - \min(x_{ij})} \quad (2)$$

$$e_j = -\frac{1}{\ln 1} \sum_{i=1}^n (X_{ij} / \sum_{i=1}^n X_{ij}) \ln(X_{ij} / \sum_{i=1}^n X_{ij}) \quad (3)$$

$$w_j = \frac{1 - e_j}{\sum_{i=1}^n (1 - e_j)} \quad (4)$$

$$S_i = \sum_{j=1}^m w_j X_{ij} \quad (5)$$

$$U_i = \sum_{j=1}^m w_j X_{ij} \quad (6)$$

$$T_i = \alpha S_i + \beta U_i \quad (7)$$

$$C_i = \sqrt{\frac{S_i \times U_i}{((S_i + U_i)/2)^2}} \quad (8)$$

$$D_i = \sqrt{C_i \times T_i} \quad (9)$$

Let $j = 1, 2, \dots, m$ denote the number of indicators; $i = 1, 2, \dots, n$ indicates the i -th province. The x_{ij} indicates the original value of the evaluation indicator, and X_{ij} represents the standardized result of the corresponding indicators. S_i and U_i represent the comprehensive evaluation indices of the supply side and demand side development of the age-friendly environment, respectively. The weights of the corresponding indicators are denoted by w_j . The α and β represent the weights assigned to the supply-side and demand-side development of age-friendly environment construction, respectively. Based on previous research experience and an analysis of the significance of supply and demand in age-friendly environment construction, this study assumes equal contribution from both aspects. Thus, α and β are assigned a value of 0.5 each. D_i indicates the coupling coordination degree of the i province.

The coupling coordination degree D_i ranges from 0 to 1, and it is categorized into ten levels (Table 1) based on the existing research classification standard [16,17].

Table 1. Coupling coordination degree classification and description.

Coupling Coordination Degree (D)	Coupling Coordination Level
(0.00, 0.10]	Extreme disorder
(0.10, 0.20]	Severe disorder
(0.20, 0.30]	Moderate disorder
(0.30, 0.40]	Mild disorder
(0.40, 0.50]	Borderline disorder
(0.50, 0.60]	Forced coordination
(0.60, 0.70]	Primary coordination
(0.70, 0.80]	Intermediate coordination
(0.80, 0.90]	Good coordination
(0.90, 0.10]	Quality coordination

2.2. Theil Index

The Thiel Index was utilized to assess the regional disparities in the coupling coordination degree between the supply and demand for age-friendly environment construction across the 31 provinces in China. This index offers the benefits of straightforward calculation and distinct decomposition [18–20]. The calculation formula is provided below:

$$T = \frac{1}{n} \sum_{i=1}^n \frac{y_i}{\mu} \ln \frac{y_i}{\mu} \quad (10)$$

where, n is the number of research samples, in this paper $n = 31$; μ is the average value of supply-demand coupling coordination degree of the aged-friendly environment in 31 provinces of China. y_i refers to the coupling degree of supply and demand in province i . The Theil index can be further decomposed into inter-regional differences T_b and intra-regional differences T_w , as follows:

$$T = T_b + T_w \quad (11)$$

$$T_b = \sum_{k=1}^4 \frac{n_k}{n} \times \frac{y_k}{\mu} \ln \frac{y_k}{\mu} \quad (12)$$

$$T_w = \sum_{k=1}^4 \frac{n_k}{n} \times \frac{y_k}{\mu} \times T_k = \sum_{k=1}^4 \frac{n_k}{n} \times \frac{y_k}{\mu} \left(\frac{1}{n_k} \sum_{p=1}^{n_k} \frac{y_{kp}}{y_k} \ln \frac{y_{kp}}{y_k} \right) \quad (13)$$

$$I_b = \frac{T_b}{T} \quad (14)$$

$$I_w = 1 - I_b = \frac{T_w}{T} \quad (15)$$

Among them, $k = 1, 2, \dots, 4$ represents the four divisions, y_k refers to the average of supply-demand coupling coordination degree of age-friendly environment in the provinces in group k , n_k refers to the number of provinces in group k , y_{kp} represents the coupling coordination degree of the p province in region k , and I_b (I_w) refers to the contribution degree of inter-regional differences to the total differences (the contribution rate of intra-regional differences to the total differences). The overall difference and contribution rate of supply-demand coupling coordination degree of the age-friendly environment in 31 provinces in China were calculated; further, the identification of the sources of regional differences in China's elderly-friendly environment construction.

2.3. Spatial Autocorrelation Analysis

Due to the difference in economic level, resource layout, policy environment, and other factors, the coupling coordination degree of supply and demand of an age-friendly environment is also different in different provinces. Spatial autocorrelation may be the reason for the differences in coupling coordination degree. In order to ensure the rationality of the spatial econometric model to test the convergence of coupling coordination degree in various provinces, this paper adopts Moran's I index to measure spatial correlation, and the calculation formula is as follows [21,22]:

$$\text{Moran's } I = \frac{\sum_{i=1}^n \sum_{j=1}^m \omega_{ij} (\text{EFCD}_i - \overline{\text{EFCD}}) (\text{EFCD}_j - \overline{\text{EFCD}})}{s^2 \sum_{i=1}^n \sum_{j=1}^m \omega_{ij}} \quad (16)$$

$$I_i = \frac{(\text{EFCD}_i - \overline{\text{EFCD}})}{s^2} \sum_{j=1}^m \omega_{ij} (\text{EFCD}_j - \overline{\text{EFCD}}) \quad (17)$$

where ω_{ij} represents the weight matrix. When provinces i and j are adjacent, the weight is 1; when provinces j are not adjacent, the weight is 0; The value range of Moran's I index is $[-1, 1]$. An index greater than 0 indicates a positive spatial correlation. When the value is close to 1, it indicates that there are similar high values and high values, and low values are adjacent to low values. A value less than 0 indicates a negative spatial correlation and a value close to 1 indicates that dissimilar attributes cluster together (i.e., a high value is adjacent to a low value or a low value is adjacent to a high value). Zero means space is not correlated.

2.4. Spatial Metrology Model

For panel data, common models include spatial error model (SEM), spatial lag model (SAR), and spatial Durbin model (SDM). Due to the universal spatial spillover effect of spatial units, the spatial metrology model was tested and derived by Feng Yanchao [23]. This paper selects the model through empirical analysis, and finally decides to use the spatial Durbin model (SDM):

$$\text{Efcd}_{it} = \rho \sum_{j=1}^m \omega_{ij} \text{efcd}_{ij} + \beta X_{it} + \sum_{j=1}^m \omega_{ij} X_{ij} \theta + \mu_i + \pi_i + \varepsilon_{it} \quad (18)$$

Among them, $i = 1, 2, \dots, n$ indicates the i -th province; $j = 1, 2, \dots, m$ denote the number of indicators; $t = 2014, 2015, \dots, 2020$ represent the year. Efcd_{it} stands for the coupling coordination degree of supply and demand of an age-friendly environment. X represents a set of explanatory control variables, including five aspects: the size of the elderly population (PS), economic development level (EL), health service security (HS), ecological construction level (EC), and humanistic care level (HC). The specific indicators included are shown in Table 2. The θ is the constant regression parameter to be estimated.

ρ is the coefficient after space; ω_{ij} represents the spatial weight matrix; μ_i and π_i are individual effects and time effects, respectively. The ε_{it} is the perturbation term.

Table 2. Indicators contained in various aspects of the explanatory control variable.

Primary Index	Secondary Index	
Health Service Security (HS)	Number of urban and rural basic old-age insurance (Ten thousand persons)	X1
	Number of people in social security and social organizations (Ten thousand persons)	X2
	Number of beds per 1000 elderly people (sheet)	X3
Ecological Construction Level (EC)	Per capita green park area (m ²)	X4
	Green coverage rate of built-up area (%)	X5
Humanistic Care Level (HC)	Library holdings per capita (volume)	X6
	Number of Performing Arts Organizations (place)	X7
	Number of nursing beds per 1000 elderly (sheet)	X8
Economic Development Level (EL)	Per capita GDP (100 million CNY/square kilometer)	X9
	Gross regional product per capita (CNY)	X10
Size of the elderly population (PS)	Number of elderly people over 65 years old (Ten thousand persons)	X11

2.5. Data Sources and Indicator System

This empirical study focuses on thirty-one provinces, municipalities directly under the Central Government, and autonomous regions in China (excluding Hong Kong, Macao, and Taiwan). To facilitate empirical analysis and comparison of the development level, the regions were determined based on the principles of regional division and economic development differentiation, with reference to relevant research conducted by scholars [24–26]. The thirty-one provinces are categorized into four regions: Northeast region, Eastern region, Central region, and Western region. The original data for this study consists of national panel data from 2014 to 2020, obtained from sources such as the China Statistical Yearbook, China Social Statistical Yearbook, and Statistical Bulletin of National Economic Development. Following data standardization, the Bayesian interpolation method is applied to predict and fill in missing values.

Drawing on the principles of systematic, scientific, and comprehensive construction of index systems, and guided by the theory of active aging, this study is based on the examination of the “Global Guide to the Construction of Age-Friendly Cities” and the “Evaluation Indicators of Livable (suitable for tourism) Cities for the Elderly in China”, incorporating the index selection ideas of numerous scholars. For instance, Zhao Dongxia et al. identified the supply index for age-friendly environment construction based on four types of resources: living services, medical care, cultural and sports activities, and the living environment [27]. Zhang Chunmei et al. proposed an evaluation index system for the human settlement environment of elderly livable communities, considering five dimensions: social system, natural system, living system, facility system, and human system [28]. Building upon the findings of other scholars in related fields [29,30], a comprehensive age-friendly environment supply-demand coupling and coordinated evaluation index system, consisting of 26 indicators, was constructed from various aspects surrounding the supply-demand subsystem of the age-friendly environment (Table 3). The supplied index for the age-friendly environment is primarily chosen based on three aspects: space-friendliness, service-friendliness, and humanity-friendliness, encompassing seven areas: public facilities, transportation, outdoor space, health services, old-age services, social security, and social

participation. The demand index for the age-friendly environment is primarily constructed based on the needs of the elderly population, considering two aspects: population vitality and economic vitality.

Table 3. Supply and demand index system of the age-friendly environment.

	Primary Index	Secondary Index	Tertiary Index	Attribute
Age-friendly environment matching supply and demand	Supply-side	Public facilities	Number of public libraries (place)	+
			Library holdings per capita (volume)	+
			Number of museum institutions (place)	+
			Number of Performing Arts Organizations (place)	+
		Transportation trip	Number of public electric cars per 10,000 people (vehicle)	+
			Per capita urban road area (m ²)	+
		Outdoor space	Per capita urban green area (m ²)	+
			Per capita green park area (m ²)	+
			Harmless treatment rate of domestic waste (%)	+
			Green coverage rate of built-up area (%)	+
		Health service	Number of medical institutions (place)	+
			Number of beds per 1000 elderly people (sheet)	+
			Number of health technicians for the elderly per 1000 persons (person)	+
		Elderly care service	Number of elderly care institutions (place)	+
			Number of retirement beds (ten thousand sheets)	+
			Number of nursing beds per 1000 elderly (sheet)	+
		Social security	Number of urban and rural basic old-age insurance (Ten thousand persons)	+
			Number of basic old-age insurance for urban workers (Ten thousand persons)	+
		Social participation	Number of Members of Grassroots Elderly Associations (person)	+
			Number of people in social security and social organizations (Ten thousand persons)	+
	Demand side	Population vitality	Number of elderly people over 65 years old (Ten thousand persons)	+
			Elderly dependency ratio (%)	+
		Economic vitality	Per capita GDP (100 million CNY/square kilometer)	+
			Gross regional product per capita (CNY)	+
			Per capita disposable income (CNY)	+
			Per capita consumption expenditure (CNY)	+

3. Results

3.1. Coupling Coordination Degree Analysis

Illustrated in Figure 1, when considering the entire country, the coupling coordination degree of the age-friendly environments supply and demand system exhibited an inverted U-shaped development trend from 2014 to 2020, indicating a consistent state of weak coordination. This indicates that there has not been a significant change in the development of China's age-friendly environment supply and demand system. Specifically, regarding the time aspect, the coupling coordination degree increased from 0.531 to 0.545 between 2014 and 2016 but decreased from 0.547 to 0.516 between 2017 and 2020. This demonstrates that the coordination between the supply and demand of China's age-friendly environment is still characterized by a mismatch and mutual hindrance during the development process. In terms of spatial distribution, noticeable variations are observed, exhibiting a pattern of "higher in the southeast and lower in the northwest" (Figure 2).

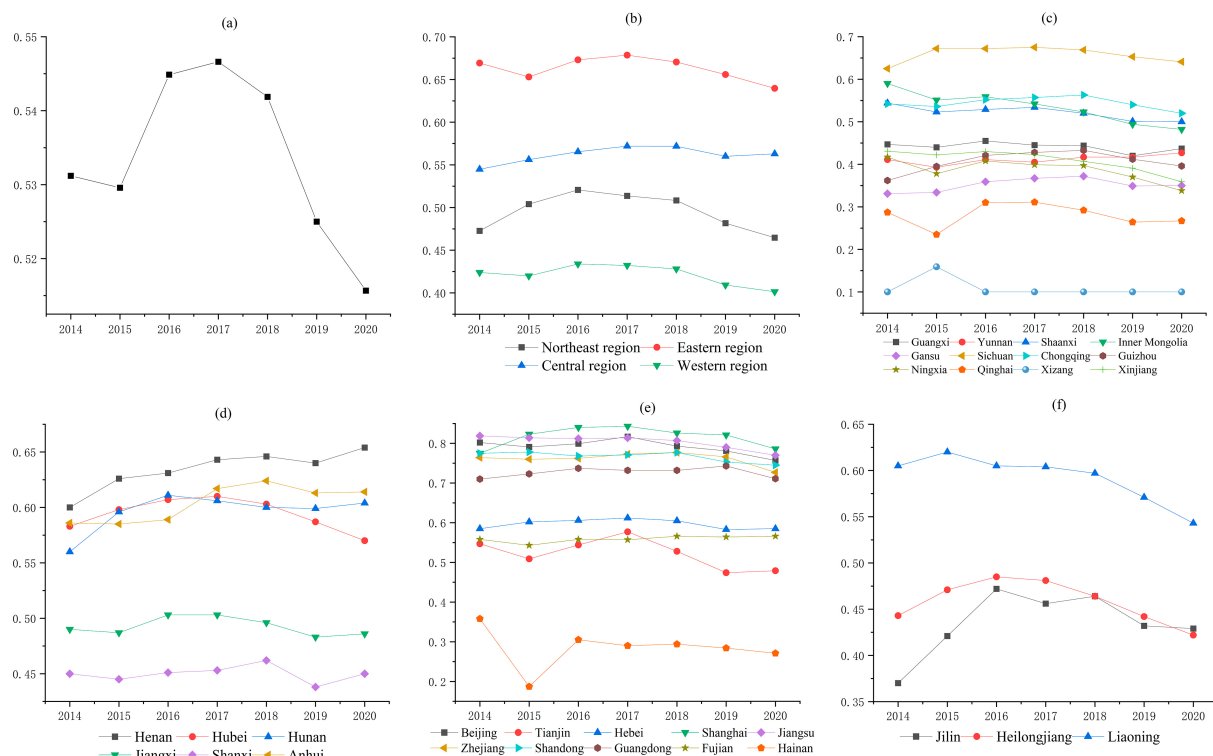


Figure 1. Coupling and coordination degree of 31 provinces and cities in China: (a) National coupling coordination degree; (b) Coupling coordination degree of four regions; (c) Provinces in the western region; (d) Provinces in the central region; (e) Provinces in the eastern region; (f) Provinces in the northeast region.

Considering the regional perspective, there are variations in the development level among different regions, although the development trend is similar. Specifically, in terms of time, the coupling coordination degree in Northeast China exhibits a declining trend, indicating an overall state of unbalanced development in the region. The coupling coordination degree in the eastern region, except for the decline in Hainan in 2015, does not exhibit a noticeable trend. It has an average value of 0.663, surpassing the national average of 0.534, indicating a stable primary coordinated development state. In the central region, there was a 3.34% increase in the coupling coordination degree between 2014 and 2020. The coupling coordination degree in the western region is the lowest among the regional plates, with an average value of only 0.421, indicating a significant gap compared to the national average and the development level of more advanced regions. With the exception of Hainan, all eastern regions are experiencing coordinated development, and 60% of the provinces are in an intermediate stage of coordinated development. All central regions, except for Jiangxi, are undergoing coordinated development, with 50% of them in the primary coordinated development state. However, Northeast China is approaching a state of unbalanced development. Approximately 58.3% of the western region is experiencing dysfunctional development, particularly Tibet, which has reached a stage of severe dysfunctional development. Consequently, the western region is the only region within the regional plate with provinces facing significant dysfunction.

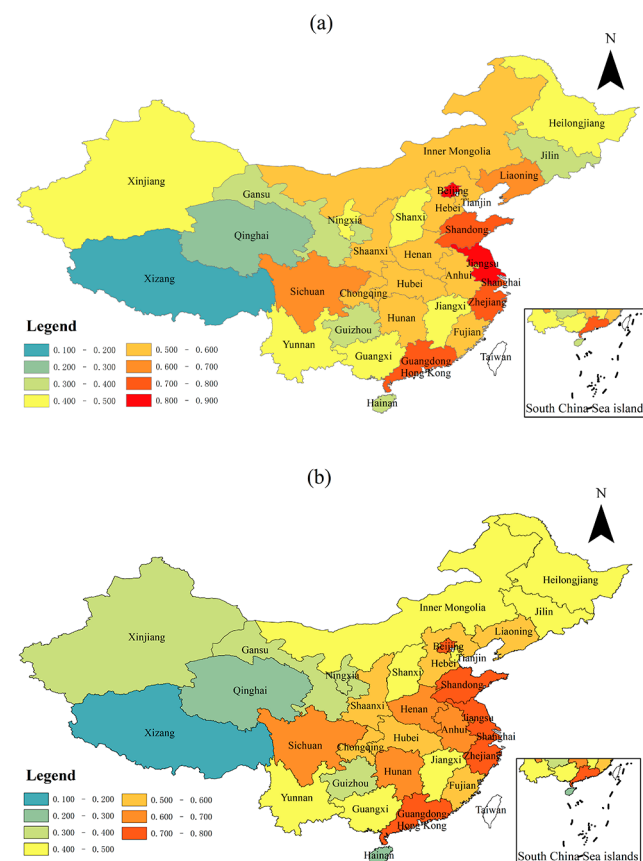


Figure 2. Spatial pattern and evolution of supply-demand coupling and coordination of China's age-friendly environment in 2014 and 2020: (a) Coupling coordination degree in 2014; (b) Coupling coordination degree in 2020.

Looking at the provincial units, the eastern region is predominantly represented by provinces with the highest average coupling coordination degree from 2014 to 2020. Shanghai and Jiangsu demonstrate good coordination, while Beijing, Zhejiang, Shandong, and Guangdong exhibit primary coordination. Additionally, 12 provinces, including Anhui, Henan, and Sichuan, demonstrate basic coordination. Eight provinces, including Jiangxi, Heilongjiang, and Guangxi, are approaching a state of unbalanced development. The remaining 6 provincial units are experiencing varying degrees of dysfunctional development. In 2020, 12 provinces witnessed changes in the degree of coupling coordination compared to 2014. Among them, Henan, Anhui, and Hunan demonstrated an improved coupling coordination degree, transitioning from a barely coordinated degree to a primarily coordinated degree. On the other hand, Jiangsu and Beijing experienced a decrease in the coupling coordination degree, transitioning from a good coordination degree to an intermediate coordination degree. Inner Mongolia and Tianjin are approaching an imbalanced state from barely coordinated, whereas Xinjiang and Ningxia have transitioned from near disorder to mild disorder. The number of regions categorized as experiencing dysfunctional development increased from 13 in 2014 to 15 in 2020. This indicates that while the supply of age-friendly environments is consistently improving, the pressure generated by population aging intensification has led to a reverse development in the coupling coordination degree of supply and demand.

3.2. Theil Index Analysis

To further analyze the underlying factors influencing the supply-demand coupling coordination degree of China's age-friendly environment, the Theil index was employed to assess regional development disparities. The magnitude of the Theil index reflects the

regional disparity in the supply-demand coupling coordination degree of China's age-friendly environment. As depicted in Figure 3, the overall difference exhibits a phased fluctuation pattern over time. Between 2014 and 2016, a fluctuating trend was observed, with the overall Thiel index declining from 0.00298 to 0.00275. Between 2017 and 2020, a pattern of "sharp increase followed by a slight decrease" emerged, resulting in an overall rise of the Thiel index from 0.00287 to 0.00306. It can be observed that while the overall Thiel index demonstrates a generally increasing trend, the magnitude of change remains limited. This suggests that the regional disparities in the supply-demand coupling coordination degree of China's age-friendly environment are growing, but the overall difference is currently not substantial. Regarding regional disparities, the eastern region exhibits the highest discrepancy, with an average Theil index value of 0.00389, significantly surpassing the inter-regional average of 0.00226. However, the disparities between the northeast and central regions are relatively smaller. In terms of regional difference contribution, the inter-regional disparity makes a considerably greater contribution compared to the intra-regional disparity. Between 2014 and 2020, the contribution of inter-regional disparities increased from 73.37% to 78.17%, with the western region accounting for 34.09%, becoming the primary contributor to the total difference. In contrast, the contribution of intra-regional disparities decreased from 26.63% to 21.83%. In recent years, inter-regional disparities in development status and resource allocation have progressively widened, constituting the primary factor contributing to the overall difference, whereas intra-regional disparities in provincial and municipal development have diminished. Therefore, in enhancing the balance of the coupling coordination degree, it is crucial not only to address the development imbalance between provinces and cities but also to emphasize regional balance.

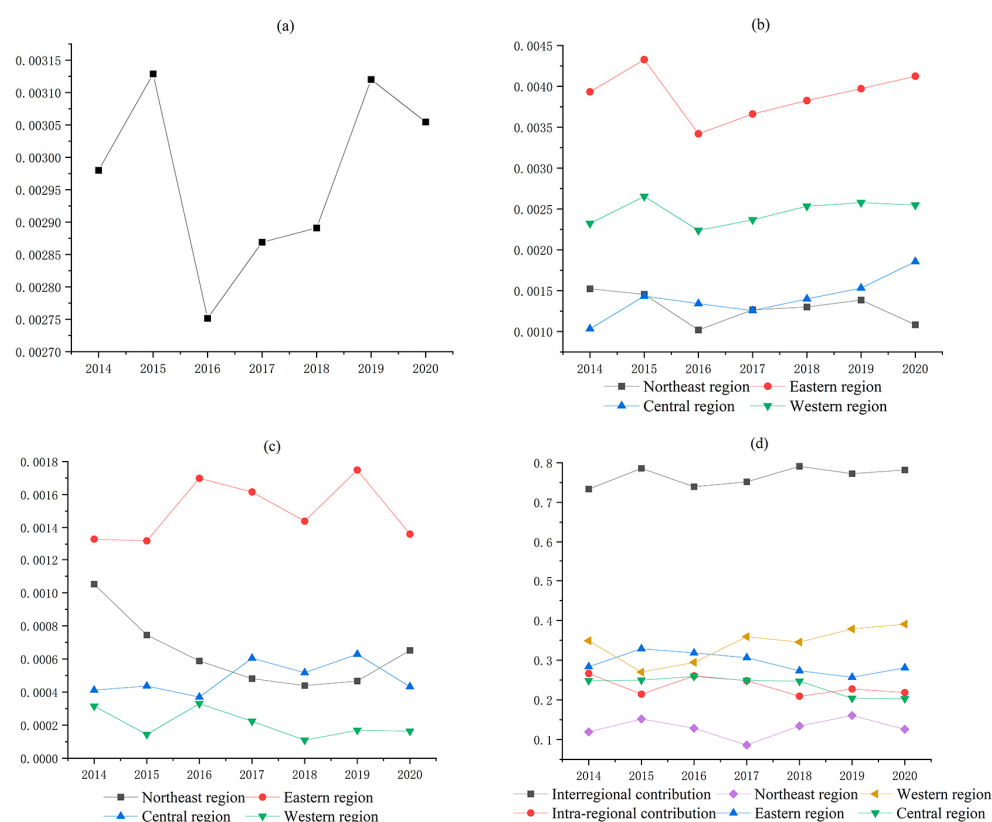


Figure 3. Thiel index variation trend of coupling coordination degree: (a) National Thiel index value; (b) Interregional Thiel index value; (c) Thiel index value in the region; (d) Differential contribution rate.

3.3. Spatial Autocorrelation Analysis

Between 2014 and 2020, a positive spatial autocorrelation (index value ranging from 0.34 to 0.37) was observed in the agglomeration level of the age-friendly environments coupling coordination degree in China (Table 4). The results indicated a year-by-year increase in the global spatial correlation of the coupling coordination degree of the age-friendly environment in China during the study period. Additionally, all p -values of the global Moran index from 2014 to 2020 were below 0.01, indicating a significant positive spatial correlation in the agglomeration.

Table 4. Global Moran's I of coupling coordination degree.

Variables	I	E (I)	Sd (I)	z	p-Value *
2014	0.340	−0.033	0.114	3.279	0.001
2015	0.305	−0.033	0.115	2.940	0.002
2016	0.322	−0.033	0.114	3.127	0.001
2017	0.349	−0.033	0.114	3.354	0.000
2018	0.356	−0.033	0.114	3.412	0.000
2019	0.345	−0.033	0.115	3.306	0.000
2020	0.370	−0.033	0.115	3.517	0.000

Note: * 1-tail test.

The results of the global Moran Index confirm the presence of a global spatial autocorrelation in the coupled coordination degree of the age-friendly environment for the elderly in China. To gain a deeper understanding of the spatial agglomeration patterns in the local regions of the provinces regarding the coupled coordination degree of the age-friendly environment for the elderly, the agglomeration values for the sample provinces are selected for the first and last years, as well as the middle years of the research interval. Specifically, the data for the years 2014, 2016, 2018, and 2020 were utilized to create a scatter plot of the local Moran Index distribution using stata17.0. The corresponding results are presented in Figure 4 and Table 5. Additionally, ArcGIS was employed to visually represent the spatial distribution of the Moran Index in 2014 and 2020 (refer to Figure 5).

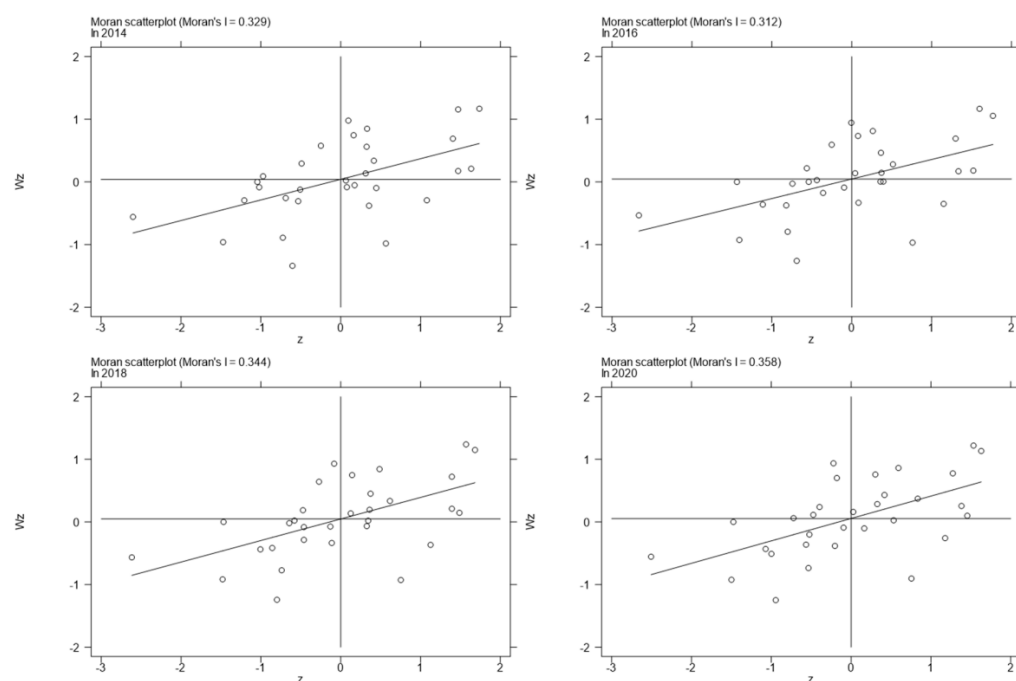


Figure 4. Local Moran index scatter plot.

Table 5. Provinces and cities included in each quadrant in 2014, 2016, 2018, and 2020.

Year	H-H (The First Quadrant)	L-H (The Second Quadrant)	L-L (The Third Quadrant)	H-L (The Fourth Quadrant)
2014	Beijing, Tianjin, Hebei, Shanghai, Fujian, Jiangsu, Zhejiang, Hubei, Anhui, Shandong, Henan	Shanxi, Jilin, Jiangxi	Heilongjiang, Guangxi, Hainan, Guizhou, Yunnan, Xizang, Gansu, Qinghai, Ningxia, Xinjiang	Liaoning, Chongqing, Hunan, Guangdong, Sichuan, Shaanxi, Inner Mongolia
2016	Beijing, Hebei, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Hubei, Chongqing	Tianjin, Shanxi, Jiangxi	Jilin, Heilongjiang, Guangxi, Hainan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	Liaoning, Hunan, Sichuan, Inner Mongolia, Guangdong,
2018	Beijing, Hebei, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Hubei, Chongqing	Tianjin, Shanxi, Jiangxi	Inner Mongolia, Xinjiang, Heilongjiang, Guangxi, Hainan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Jilin	Liaoning, Hunan, Guangdong, Sichuan
2020	Beijing, Hebei, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Hubei, Chongqing	Tianjin, Shanxi, Jiangxi, Guangxi, Guizhou	Inner Mongolia, Hainan, Heilongjiang, Xinjiang, Jilin, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia,	Liaoning, Guangdong, Hunan, Sichuan

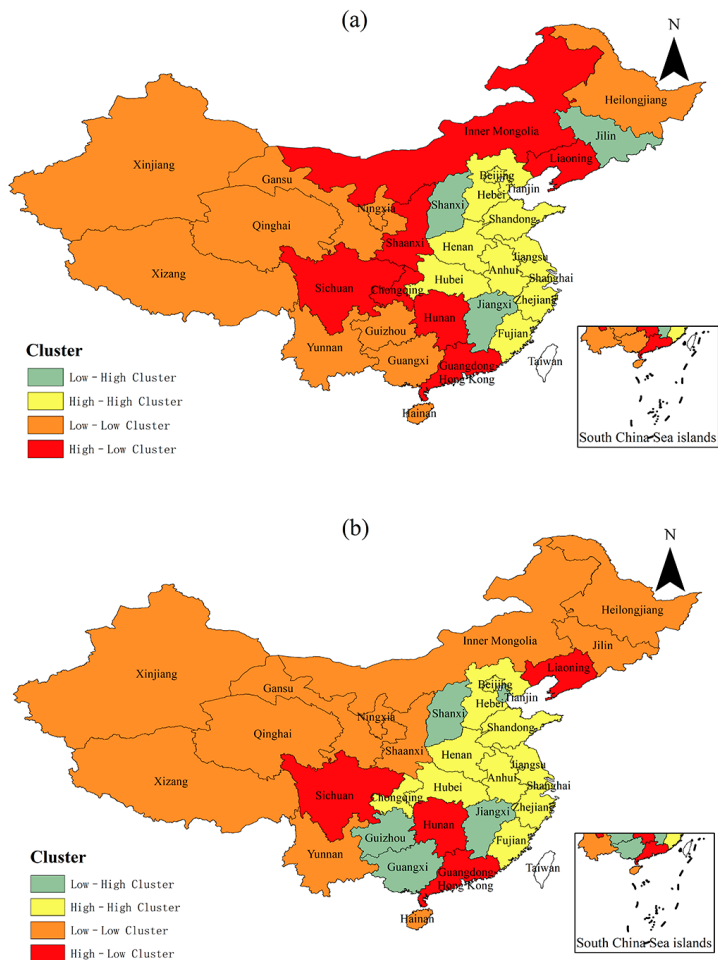


Figure 5. Local spatial autocorrelation (LISA) cluster diagram: (a) 2014; (b) 2020.

In general, the coupling coordination degree of the middle-aged and elderly-friendly environment varies across the four years, but most of them exhibit a trend of “L-L” agglomeration and “H-H” agglomeration. During the period from 2014 to 2020, the number of provinces in the first quadrant was 11, while the number of provinces in the third quadrant increased from 10 to 13. These findings suggest a clear coupling and coordination of age-friendly environments among provinces in China, accompanied by a significant positive spatial correlation. Put differently, the coupling coordination degree between the supply side and demand side in the age-friendly environment system exhibits a clear spatial spillover effect.

In 2020, compared to 2014, the eastern coastal areas including Beijing, Shanghai, Jiangsu, Zhejiang, and Shandong enjoyed improved geographical advantages, resulting in relatively high coupling coordination degrees. The surrounding areas also exhibited high coupling coordination, forming an “H-H” cluster. Shanxi and Jiangxi exhibit a low level of coupling coordination. Despite being adjacent to regions with high coupling coordination levels, they demonstrate poor correlation with the surrounding areas. Therefore, efforts are needed to enhance their ability for coordinated development with the surrounding regions, placing them in the “L-H” cluster. Heilongjiang, Yunnan, Hainan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang exhibit a low level of coupling coordination. Their adjacent regions also display low coupling coordination levels, categorizing them as part of the “L-L” cluster. The coupling coordination levels of Liaoning, Hunan, Guangdong, and Sichuan regions are higher than those of the surrounding regions. However, they do not exhibit a radiating role in driving the development of the surrounding regions, placing them in the “H-L” cluster with spatial heterogeneity. Over the course of six years, certain regions have experienced cluster transitions influenced by radiation effects from the surrounding areas. For instance, Guangxi and Guizhou have shifted from the “L-L” cluster to the “L-H” cluster. Similarly, Tianjin has transitioned from an “H-H” cluster to an “L-H” cluster, while Inner Mongolia and Shaanxi have changed from an “H-L” cluster to an “L-L” cluster.

3.4. Analysis of Regression Results of Spatial Econometric Model

Enhancing the supply level of an age-friendly environment can stimulate demand development, while the development of demand, in turn, contributes to further improving the supply output of an age-friendly environment. Consequently, establishing and maintaining a coordinated and mutually supportive relationship between the two can yield positive social and economic outcomes. However, in studying the relationship between variables, it is important to consider their spatial interdependence. The supply-demand balance of the age-friendly environment in a particular area can be influenced by the surrounding regions, and this influence has a reciprocal effect. Consequently, this violates the assumption of the classical least squares method, necessitating the establishment of a spatial econometric model to analyze the data. By testing and analyzing the spatial econometric model, we can gain further insights into the influencing factors and spatial effects of the age-friendly environment.

3.4.1. Model Test

The LM test results (Table 6) indicate that in the spatial error model test, the Moran index, LM, and Robust LM exhibit significance within the 1% confidence interval. Similarly, in the spatial lag model test, LM and Robust LM show significance within the 5% confidence interval. To gain further clarity on selecting the spatial measurement model for age-friendly environment coupling coordination, the subsequent step involves conducting an LR test to determine whether the spatial Durbin model reduces to a spatial error model or a spatial lag model.

Table 6. LM test result.

Test	Statistic	df	<i>p</i> -Value
Spatial error:			
Moran's I	3.631	1	0.000
Lagrange multiplier	11.293	1	0.001
Robust Lagrange multiplier	9.050	1	0.003
Spatial lag			
Lagrange multiplier	3.469	1	0.063
Robust Lagrange multiplier	1.226	1	0.068

Both the LR test and Wald test yield a *p*-value of 0.000, indicating significance within the 1% confidence interval (Table 7). This confirms that the spatial Durbin model does not degenerate into a spatial error model or a spatial lag model. Furthermore, based on the Horsman test, the *p*-value of 0 indicates significance. This rejects the hypothesis that the explanatory variable is independent of the individual effect, confirming that the fixed effect surpasses the random effect [31]. Secondly, according to the LR test, the dual fixed effect outperforms the individual and time-fixed effects. Therefore, this study ultimately selects the dual fixed effect spatial Durbin model to analyze the coupling coordination degree of the age-friendly environment.

Table 7. Test results of LR and Wald.

Test Form	Chi	<i>p</i> -Value
LR (SDM and SAR)	45.10	0.000
LR (SDM and SEM)	45.50	0.000
Wald's test	191.84	0.000
Hausman	148.97	0.000
LR-test (both ind)	36.90	0.001
LR-test (both time)	322.53	0.000

3.4.2. Spatial Spillover Effect Analysis

To examine the impact of each variable on the coupling coordination degree of the age-friendly environment and explore their causal pathways, this study employs a bidirectional fixed spatial Durbin model to analyze the spatial spillover effect of each variable (Table 8). Overall, different factors exhibit distinct influences on the coupling coordination degree of the age-friendly environment in the region, leading to varying degrees of spatial spillover to the surrounding areas. In terms of overall impact, factors such as per capita green park area (X4), the green coverage rate of built-up areas (X5), gross regional product per capita (X10), and the number of individuals aged 65 and above (X11) significantly influence the coupling coordination degree of the age-friendly environment. Specifically, the direct effect coefficient of the gross regional product per capita (X10) is 0.110, which is statistically significant at the 1% level, while the indirect effect coefficient is positive but not statistically significant. This indicates that gross regional product per capita has a positive effect on promoting the coupling coordination degree of the age-friendly environment within the province. However, due to variations in provincial policies, there is a lag in the implementation of construction investment in neighboring provinces. The direct effect coefficient of the number of elderly people over 65 years old (X11) is 0.137, which is statistically significant at the 1% level, while the indirect effect coefficient is negative but not statistically significant. This is because the size of the elderly population directly influences the demand level for an age-friendly environment, which, in turn, affects its development level. However, due to the accelerated aging process of the population, the influence of population spatial agglomeration is concentrated within the province,

and the neighboring provinces have limited driving capacity. Furthermore, the effect decomposition of the number of beds per 1000 elderly people (X3) and the number of nursing beds per 1000 elderly (X8) also exhibit a similar pattern, with direct positive significance and indirect insignificance. This indicates that enhancing the level of service supply directly associated with the age-friendly environment has a positive influence on improving the overall coupling coordination degree. However, the spillover effect is not significant, which could be attributed to the negative impact of the service competition mechanism.

Table 8. Results of spatial Durbin model estimation and spatial effect decomposition.

Variables	Main	Spatial	Variance	LR-Direct	LR-Indirect	LR-Total
X1	0.00708 (0.113)			0.0104 (0.109)	−0.133 (0.217)	−0.122 (0.230)
X2	−0.0451 (0.0424)			−0.0443 (0.0405)	0.0450 (0.0827)	0.000726 (0.0900)
X3	0.0588 *** (0.0154)			0.0607 *** (0.0158)	−0.0217 (0.0301)	0.0390 (0.0331)
X4	0.0677 *** (0.0212)			0.0682 *** (0.0205)	0.00451 (0.0401)	0.0727 (0.0496)
X5	−0.138 *** (0.0512)			−0.00553 (0.0185)	−0.114 *** (0.0412)	−0.119 *** (0.0449)
X6	0.0334 (0.0792)			0.0213 (0.0754)	0.143 (0.144)	0.164 (0.151)
X7	0.0255 (0.0222)			0.0235 (0.0218)	0.0165 (0.0361)	0.0399 (0.0375)
X8	0.0333 *** (0.0114)			0.0353 *** (0.0111)	−0.0293 (0.0212)	0.00599 (0.0238)
X9	−0.0917 (0.149)			−0.102 (0.149)	0.0521 (0.250)	−0.0495 (0.289)
X10	0.109 *** (0.0306)			0.110 *** (0.0300)	0.0254 (0.0600)	0.135 ** (0.0657)
X11	0.133 *** (0.0461)			0.137 *** (0.0457)	−0.0707 (0.0817)	0.0664 (0.0911)
rho		−0.262 *** (0.101)				
sigma2_e			0.000188 *** (1.81×10^{-5})			
R ²	0.3409					
Log-L	621.5073					

Note: ***, ** represent significance at the levels of 1%, 5%, respectively.

3.4.3. Regional Heterogeneity Analysis

Related variables may also have spillover effects on neighboring provinces when influencing the coupling coordination degree of the age-friendly environment in different regions. To further investigate the varying impact levels of different influencing factors on the development of the age-friendly environment in different regions, based on the aforementioned spatial correlation analysis, specific analysis is conducted on the provinces situated in two agglomeration areas, high-high and low-low, in terms of their age-friendly environment coupling coordination degree. The results are presented in Table 9.

The results revealed that in the high-high agglomeration region, the direct coefficient of the gross regional product per capita (X10) level was significantly positive (0.214 ***) and the indirect effect coefficient was significantly negative (−0.257 ***). This suggests that in the high-high agglomeration region, gross regional product per capita directly promotes the enhancement of the coupling coordination degree of the age-friendly environment in the

province. Conversely, neighboring provinces experience a counteractive inhibition effect due to resource factor demands. The size coefficients of the elderly population (X11) are all significantly positive in the high-high agglomeration area, indicating that the growth of the elderly population has a positive promoting effect on the coupling coordination degree of the age-friendly environment in the province and neighboring provinces. This suggests that there is a significantly positive spatial spillover effect in this region. In the low-low agglomeration area with a low age-friendly environment coupling coordination degree, the direct coefficient of the gross regional product per capita (X10) level is significantly positive (0.218 **), while the indirect effect is not significant (0.167). This indicates that in the low agglomeration area, gross regional product per capita promotes the enhancement of the age-friendly environment coupling coordination degree in the province. However, it does not significantly promote the coupling coordination degree of the age-friendly environment in neighboring provinces. The size coefficient of the elderly population (X11) is not significant, suggesting that in low-low agglomeration areas, the expansion of the elderly population size still has room for development, as both their own provinces and neighboring provinces have relatively low development levels. Consequently, it does not directly impact the overall development level.

Table 9. Results of spatial Dubin model estimation and spatial effect decomposition for subregions.

Variables	H-H				L-L			
	Main	LR-Direct	LR-Indirect	LR-Total	Main	LR-Direct	LR-Indirect	LR-Total
X1	0.262 * (0.145)	0.0832 (0.0831)	0.220 * (0.127)	0.304 ** (0.149)	0.806 (0.608)	1.044 (0.649)	−1.031 (0.895)	0.0133 (0.839)
X2	0.146 ** (0.0741)	−0.0629 (0.0389)	0.146 ** (0.0666)	0.0835 (0.0844)	−0.217 (0.142)	−0.152 (0.129)	−0.205 (0.179)	−0.357 (0.223)
X3	0.00224 (0.0343)	0.0540 *** (0.0174)	−0.00532 (0.0283)	0.0487 (0.0394)	−0.00944 (0.0302)	−0.0106 (0.0384)	0.00655 (0.0492)	−0.00402 (0.0381)
X4	−0.121 * (0.0677)	−0.0515 (0.0321)	−0.0988 (0.0627)	−0.150 * (0.0807)	0.0517 (0.0414)	0.0551 (0.0400)	−0.0121 (0.0475)	0.0430 (0.0605)
X5	0.0929 ** (0.0421)	0.0778 *** (0.0244)	0.0706 * (0.0426)	0.148 *** (0.0567)	0.0153 (0.0311)	0.00859 (0.0348)	0.0216 (0.0308)	0.0302 (0.0351)
X6	0.180 * (0.0925)	−0.121 ** (0.0570)	0.178 ** (0.0853)	0.0566 (0.0915)	0.532 ** (0.233)	0.644 ** (0.264)	−0.446 (0.321)	0.198 (0.304)
X7	0.115 *** (0.0258)	0.0749 *** (0.0160)	0.0920 *** (0.0221)	0.167 *** (0.0259)	−0.210 (0.129)	−0.102 (0.138)	−0.430 ** (0.194)	−0.532 *** (0.197)
X8	0.0526 * (0.0281)	0.00104 (0.0138)	0.0463 * (0.0250)	0.0474 * (0.0274)	0.0871 *** (0.0204)	0.0838 *** (0.0209)	0.0154 (0.0191)	0.0992 *** (0.0233)
X9	4.036 *** (1.161)	−0.475 (0.645)	3.733 *** (1.068)	3.258 *** (1.097)	−4.134 (3.178)	−3.309 (3.804)	−3.939 (6.194)	−7.249 (5.309)
X10	−0.245 ** (0.101)	0.214 *** (0.0739)	−0.257 *** (0.0957)	−0.0434 (0.116)	0.256 *** (0.0661)	0.218 ** (0.0961)	0.167 (0.187)	0.385 *** (0.129)
X11	0.309 *** (0.0947)	0.237 *** (0.0411)	0.241 *** (0.0825)	0.479 *** (0.108)	0.534 *** (0.207)	0.601 *** (0.199)	−0.267 (0.232)	0.335 (0.286)

Note: ***, **, * represent significance at the levels of 1%, 5%, and 10%, respectively.

In conclusion, the same influencing factors have varying effects on the improvement of the coupling coordination degree of age-friendly environments in different regions. Consequently, different regions prioritize and tend to improve the coupling coordination degree of age-friendly environments differently, and policy recommendations should consider this heterogeneity.

4. Conclusions and Suggestions

Using panel data from 2014 to 2020 encompassing 31 provinces in China, we constructed an evaluation index system for age-friendly environments under the guidance of the active aging theory. Furthermore, we empirically analyzed the coupling and coordination relationship between the supply and demand of age-friendly environments, considering factors such as development characteristics, regional differences, influencing factors, and spatial effects. The study yielded the following conclusions:

Firstly, with respect to time, the overall coupling coordination degree exhibits an inverted U-shaped development trend from 2014 to 2020, characterized by a “rise and fall” pattern. Specifically, among the four regions, only the central region demonstrated a gradual upward trend, while the remaining regions exhibited a decline. From the perspective of provincial units, the eastern regions, including Jiangsu, Shanghai, Shandong, Beijing, and other provinces, exhibit the highest level of coupling coordination. Owing to the demand pressure resulting from the intensifying aging population, the coupling coordination degree between supply and demand exhibits a reversed development pattern, leading to an increase in the number of imbalanced development categories from 13 in 2014 to 15 in 2020. Spatially, the coupling coordination is higher in the southeast and lower in the northwest. Specifically, the distribution pattern is as follows: Eastern region > Central region > Northeast region > Western region.

Secondly, considering the regional disparities in coupling coordination degree, the overall Thiel index exhibits a slight upward trend, and the regional gaps are gradually widening, albeit not substantial at present. Regarding inter-regional development disparities, the pattern is evident. The gap between the eastern and western regions is relatively substantial, whereas the gap between the central and western regions is relatively narrower. In terms of intra-regional development disparities, the eastern, central, and western regions exhibit fluctuating downward trends, whereas the northeast region demonstrates a sustained, slight upward trend.

Lastly, the coupling coordination degree exhibits substantial spatial correlation and spatial spillover effects. The level of agglomeration in age-friendly environment coupling coordination demonstrated positive spatial autocorrelation, exhibiting a gradual and continuous upward trend and displaying noteworthy spatial interdependence. Regarding comprehensive influence, factors such as per capita green park area, the green coverage rate of built-up areas, per capita gross regional product, and the number of elderly individuals over 65 years old exert a noteworthy impact on the coupling coordination degree of the age-friendly environment. Concerning regional spillover effects, the impact of the same influencing factor (e.g., gross regional product per capita) on the coupling coordination degree of the age-friendly environment varies between H-H agglomeration areas and L-L agglomeration areas.

Considering the current situation and challenges in achieving coordinated development between the age-friendly environment and the regional economic level, the following suggestions are proposed:

Firstly, achieving a balance between supply and demand and promoting balanced development are imperative. It is crucial to elucidate the features of coordinated development within the supply and demand subsystem. In regions where supply surpasses demand, leveraging intelligent tools such as big data to precisely identify the needs of the elderly population and fine-tune the scale and content of supply is essential. In regions where demand exceeds supply, issues will be identified and addressed through pilot demonstration projects focused on age-friendly cities and livable communities, ensuring timely access for a greater number of elderly individuals to the outcomes of constructing age-friendly living environments.

Secondly, fostering a balanced development through regional coordination. Taking into account the existing spatial pattern and distribution characteristics, it is important to harness the influence of regions and provinces with higher levels of development. Enhance regional cooperation, adopt the development model of metropolitan areas and network

structures, leverage the resource influence of the Beijing-Tianjin-Hebei region and the eastern coastal region, and achieve mutual benefit and win-win outcomes. Strengthen scientific and technological support, utilize digital technology, intelligent operations, overcome regional administrative barriers, and mitigate disorderly inter-regional competition.

Lastly, advancing high-quality development through the cultivation of supporting industries. The development of age-friendly environmental infrastructure in China is not keeping up with the rapid pace of population aging. Hence, it is crucial to mobilize social forces, stimulate market vitality, and enhance the construction level of the elderly care environment. Expedite policy formulation and support, and encourage and guide enterprises and markets to actively engage in the development of an age-friendly environment. The “silver economy” will be integrated with new urban development, healthcare, financial services, and other market opportunities to nurture the “silver economy,” stimulate silver consumption, and drive industrial upgrading.

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