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The Spatial Pattern and Dynamic Evolution of High-Quality Economic Development in the Chengdu-Chongqing Twin-City Economic Circle

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Abstract

To depict the spatial pattern and dynamic evolution of high-quality economic development in the Chengdu-Chongqing Twin-City Economic Circle, this paper takes the 16 prefecture-level cities of the region as the research subjects. A 19-indicator system is established based on five dimensions: innovation, coordination, green development, openness, and sharing. The Entropy-weight TOPSIS method is used to measure the high-quality economic development index of each city for the years 2011, 2017, and 2023. On this basis, a modified gravity model is employed to calculate the economic connection strength between cities and construct a spatial association network by binarizing the results. UCINET is used to reveal network structural characteristics and their changes from the perspectives of network density, centrality, and cohesion subgroups. The results indicate that: (1) The regional high-quality development level shows an overall upward trend. The spatial pattern evolves from a "dual-core polarization" in 2011 to a "single-core dominance with hierarchical differentiation" in 2017, and forms a gradient structure of "one core leading, multi-level support, and a mid-to-high level as the main body" in 2023. Cities at lower levels disappear, and the overall regional development quality significantly improves; (2) The number of inter-city connections and network density slightly increases but remains relatively low overall. Regional connections have strengthened, but the collaborative network is not yet closely formed; (3) The centrality structure shows a clear "core-hub-periphery" hierarchy, with Chongqing's spillover and intermediary bridge role continuously strengthening, Chengdu maintaining strong absorption and core aggregation advantages, and cities like Yibin and Zigong showing increased spillover capabilities, while some peripheral cities remain on the network's edges; (4) Cohesion subgroups have long been differentiated into four sectors, with members adjusting over time. Inter-sectoral connections are generally stronger than intra-sectoral ties, indicating that cross-sectoral collaboration is more critical to the network's operation.

Keywords

Social Network Analysis; High-Quality Development; Gravity Model; Spatial Association Network.

1. Introduction

The report of the 19th National Congress of the Communist Party of China clearly pointed out that China’s economy has entered a new stage of high-quality development. It is essential to comprehensively promote the optimization of economic structure, innovation-driven development, green development, and deepen regional coordinated development. As the most important economic growth pole in western China, the Chengdu-Chongqing Twin-City Economic Circle undertakes the responsibility of promoting regional integration, driving innovation-led development, and achieving green transformation. Located at the intersection

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of the upper reaches of the Yangtze River and the Belt and Road Initiative, the Chengdu-Chongqing region is the core area for high-quality economic development in western China. The spatial structural characteristics of its high-quality economic development not only have a profound impact on advancing the strategy of large-scale development in the western region but also play a critical role in building a new development pattern that focuses on the domestic economic cycle and promotes mutual reinforcement between domestic and international cycles.

With the deepening development of the Chengdu-Chongqing Twin-City Economic Circle, disparities in the high-quality economic development of cities within the region are gradually becoming evident. Scientifically analyzing and assessing the level of high-quality economic development in this region, understanding its spatial pattern and changing trends, has become crucial for achieving regional coordinated development, optimizing resource allocation, and enhancing the overall competitiveness of the region. By studying the multi-level and multi-directional economic interactions within the Chengdu-Chongqing region, this paper provides insights for building an economic integration mechanism for the region.

In recent years, academic research on high-quality economic development has focused on several key areas. The first category is the interpretation of the connotation of high-quality development and strategic research. High-quality development is the process of improving efficiency, fairness, safety, sustainability, and stability to meet the increasingly diverse needs of the people, promoting comprehensive transformation of the economy and society, and ultimately achieving national modernization and sustained, efficient economic development [1-4]. The second category involves research on measuring the level of high-quality development and its spatial-temporal evolution. Different scholars measure high-quality development in different ways. Some use single indicators, such as green total factor productivity [5] or GDP per capita [6]. Other scholars use comprehensive indicators to measure high-quality development, constructing indicator systems from the five dimensions of the new development concept [7]. Existing studies have shown that the Chengdu-Chongqing Twin-City Economic Circle exhibits polarization characteristics. To reduce this gap, attention should be paid to coordinated development within the region, utilizing strong government intervention and effective market mechanisms to allocate resources and achieve positive interaction between economic development and population flow [8].

Currently, the research on high-quality development in the Chengdu-Chongqing Twin-City Economic Circle has formed a preliminary theoretical framework, but there are still some research gaps. First, most existing studies focus on a single city level or the horizontal connections between a city and its surrounding cities, with less focus on inter-city regional collaborative governance and the complex networked relationships formed by diversified and multi-level exchanges. Therefore, exploring the structural characteristics of the Chengdu-Chongqing Twin-City Economic Circle, especially the economic cooperation models between different cities, has significant research potential and value. Second, research on the spatial connection patterns and clustering methods between cities in the Chengdu-Chongqing Twin-City Economic Circle is still insufficient. Existing literature mainly uses spatial econometric methods, focusing on the "quantitative" effects between cities, while the exploration of "structural" changes is relatively weak. Therefore, it is necessary to strengthen government intervention in key urban nodes in the Chengdu-Chongqing region, reduce the development gap between cities, optimize the "core-periphery" structure, and promote higher-level coordinated development among cities. In-depth research on the networked relationships between cities in the Chengdu-Chongqing Twin-City Economic Circle will not only help reveal the spatial-temporal evolution trajectory of regional economic integration but also provide theoretical foundations and practical guidance for precise policy implementation.

Based on the existing research framework, this paper calculates the economic connection values between cities in the Chengdu-Chongqing Twin-City Economic Circle for the years 2011,

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2017, and 2023 using a modified gravity model. It uses social network analysis to capture the overall economic characteristics of the region and employs network structural indicators such as the scale and intensity of inter-city networks to reflect the degree of connectivity between cities within the region. By examining from a spatial-temporal perspective, this paper explores the development process of economic integration between cities in the Chengdu-Chongqing Twin-City Economic Circle, clarifies the developmental positioning of cities in the region at the new stage of development, and provides path choices and policy recommendations for the high-quality development of the region.

2. Research Area, Data Sources, and Research Methods

2.1. Research Area

The Chengdu-Chongqing Twin-City Economic Circle covers 16 prefecture-level and above cities, including Chongqing, Chengdu, Zigong, Mianyang, Leshan, Luzhou, Yibin, Suining, Dazhou, Nanchong, Meishan, Neijiang, Ziyang, Guang'an, Deyang, and Ya'an.

2.2. Data Sources

Following the principles of data consistency, scientific accuracy, and accessibility, the data is sourced from the CSMAR database, EPS database, CEIC database, the Sichuan Provincial Statistical Yearbook, and the statistical yearbooks of various cities. Due to the multi-dimensional and multi-field nature of the evaluation indicator system, some cities have missing data for certain indicators. Linear interpolation is used to fill in the missing data for specific years.

2.3. Research Methods

2.3.1. Entropy-weight TOPSIS Method

To avoid subjective errors, this study uses the entropy-weight TOPSIS method to measure the high-quality economic development index of each city during the research period.

2.3.2. Gravity Model

This study uses the modified gravity model to depict the spatial association network of high-quality economic development in the Chengdu-Chongqing Twin-City Economic Circle. It improves upon the traditional gravity model by defining geographic distance and economic distance as the actual assessment distances between two cities, with a decay coefficient set to 2. The specific formula is:

$$R_{ij} = L_{ij}\frac{\sqrt[3]{G_iP_iH_i}\sqrt[3]{G_jP_jH_j}}{\left(\frac{D_{ij}}{g_i-g_j}\right)^2},\ L_{ij} = \frac{H_i}{H_i+H_j}$$

In the formula, R_{ij} represents the gravitational intensity of high-quality development between city i and city j; G_i and G_j represent the regional GDP of city i and city j, respectively; L_{ij} denotes the gravitational coefficient between city i and city j, indicating the contribution of city i to the inter-city connection; P_i and P_j represent the permanent population of city i and city j, respectively; H_i and H_j represent the high-quality economic development indices of city i and city j; D_{ij} represents the geographical distance between the two cities; and g_i and g_j are the per capita GDP of city i and city j, respectively. The gravity matrix calculated using the modified gravity model is binarized by taking the average of each row as the threshold value. For connection units with gravitational values greater than the threshold, they are marked as 1, indicating that the city in the row has a spatial spillover effect on high-quality economic development to the city in the column. For connection units with gravitational values smaller

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than the threshold, they are marked as 0, indicating that the city in the row does not have a spatial spillover effect on high-quality economic development to the city in the column.

2.3.3. Social Network Analysis

A social network can be understood as a collection of social actors and the relationships between them. Social network analysis not only reflects the characteristics of the overall network but also reveals the importance of individuals within the network. In recent years, social network analysis has been widely applied. In this study, the social network analysis software UCINET 6.0 is used as an analytical tool. Based on the theories of social network analysis and the gravity model, cities are viewed as nodes in the network, and the economic relationships between cities are represented by connections between nodes. The gravity matrix is binarized, forming a binary matrix suitable for social network analysis. The network's characteristics and its evolution are analyzed through three aspects: network density, centrality, and cohesion subgroups.

Network density is calculated as the ratio of the actual number of connections between nodes to the possible number of connections, reflecting the closeness of relationships between nodes in a network. When the network density approaches 1, the connections between cities become closer.

Centrality measures the extent to which an individual is central within a network. Common metrics for centrality include degree centrality, betweenness centrality, and closeness centrality. Degree centrality describes the ability of cities to radiate outward and receive radiation, including out-degree and in-degree. Out-degree refers to the number of relationships directly initiated by the city, with a larger value indicating stronger outward radiation ability. In-degree refers to the number of relationships directly received by the city, with a larger value indicating stronger ability to receive economic radiation. Betweenness centrality reflects the control a city has over the economic connections between other cities in the network. A higher value means that the city has more influence in the network and can more effectively control or regulate economic links between other cities, making the city's core position in the economic network structure more prominent.

When certain nodes in the network have particularly close relationships and form a secondary group, such a group is called a cohesion subgroup. Cohesion subgroups simplify the complex network structure, helping to reveal the internal structure of each subgroup and the relationships between subgroups.

3. Construction of the High-Quality Development Indicator System

Many scholars have extensively studied the connotation of high-quality development, and these studies provide the theoretical foundation for constructing the economic high-quality development evaluation indicator system in this paper. Scholars such as Ren Baoping [9] and Jin Bei [1] have emphasized the key role of the five development concepts in promoting high-quality economic development, pointing out that the essence of high-quality development is to meet the increasingly diverse needs of the people in an effective and sustainable way, thus achieving a high level of economic development quality. Zhang Junkuo and others argue that high-quality development should combine efficiency and fairness, focusing on promoting a green and sustainable economic model [10]. Overall, the existing literature largely explores the quality levels of economic outcomes from the perspective of "development" and generally agrees that the core goal of high-quality development is to meet people's needs for a better life and fully implement the five development concepts. Furthermore, scholars such as Ren Baoping have also emphasized that innovation is the primary driving force for high-quality development and must further stimulate innovation vitality; coordination, as an endogenous characteristic, needs to strengthen the systematic nature of high-quality development; green development, as

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a universal model, should promote the construction of an institutional framework for high-quality development; openness is an essential path to achieving high-quality development and should promote the formation of a new high-level opening-up pattern; and shared development, as the fundamental goal, must enhance the capacity of public service provision to ensure social fairness and shared well-being for all people [9]. Therefore, based on the hierarchical nature and availability of both process and outcome indicators for economic development, this paper constructs an economic high-quality development evaluation indicator system consisting of 5 dimensions and 19 specific indicators, as shown in Table 1.

Table 1. High-Quality Development Indicator System for the Chengdu-Chongqing Region

Dimension	Evaluation Indicator	Indicator Explanation
Innovation	C1 R&D Expenditure Intensity (+)	R&D expenditure (internal) / GDP (%)
	C2 Patent Applications per 10,000 People (+)	Patent applications / Resident population (per 10,000 people)
	C3 Fiscal Expenditure on Science and Technology Intensity (+)	Fiscal expenditure on science and technology / General public fiscal budget expenditure (%)
Coordination	C4 Per Capita Regional GDP (+)	Regional GDP / Resident population (Yuan per person)
	C5 Urban-Rural Disposable Income Disparity Coefficient (-)	Urban per capita disposable income / Rural per capita disposable income
	C6 Urban-Rural Consumption Expenditure Disparity Coefficient (-)	Urban per capita consumption expenditure / Rural per capita consumption expenditure
	C7 Tertiary Industry GDP as a Percentage of Total GDP (+)	Tertiary industry added value / GDP (%)
Green	C8 Urban Green Coverage Rate (+)	Urban green coverage rate (%)
	C9 Urban Sewage Treatment Rate (+)	Sewage treated through treatment plants / Total sewage discharge ratio (%)
	C10 SO2 Emissions per Unit of GDP (-)	Industrial SO2 emissions / GDP (%)
	C11 Municipal Waste Non-hazardous Treatment Rate (+)	Non-hazardous treatment of municipal waste / Total waste generated (%)
	C12 Comprehensive Utilization Rate of General Industrial Solid Waste (+)	Comprehensive utilization of general industrial solid waste / Total industrial solid waste generation rate (%)
Openness	C13 Foreign Trade Dependency (+)	Total imports and exports / GDP (%)
	C14 Foreign Investment Utilization Intensity (+)	Actual foreign direct investment utilization / GDP (%)
Sharing	C15 Education Development Level (-)	Student-to-teacher ratio in higher education
	C16 Medical Service Level (+)	Number of health workers / Resident population (per 10,000 people)
	C17 Per Capita Private Car Ownership (+)	Private car ownership / Resident population at the end of the year (cars per 10,000 people)
	C18 Social Security Proportion (+)	Social security and employment expenditure / Total general fiscal expenditure (%)
	C19 Per Capita Road Mileage (+)	Road mileage / Resident population at the end of the year (kilometers per 10,000 people)

4. Results and Analysis

4.1. Spatial and Temporal Evolution of High-Quality Development

Using ArcGIS, a visual analysis of the high-quality economic development levels of the Chengdu-Chongqing Twin-City Economic Circle in 2011, 2017, and 2023 was conducted (Figure 1). The high-quality development index is divided into five levels. Cities with an economic high-quality

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development index in the range of 0.4321–0.5803 are classified in the fifth level, those in the range of 0.2622–0.4320 are in the fourth level, those in the range of 0.2242–0.2621 are in the third level, those in the range of 0.1312–0.2241 are in the second level, and those in the range of 0–0.1311 are in the first level.

In 2011, the Chengdu-Chongqing region displayed a distinct "dual-core polarization" spatial pattern. Chengdu and Chongqing, with high levels of economic high-quality development, were in the fifth level, representing the highlands of high-quality development. Mianyang was in the fourth level, and Deyang was in the second level. Cities in the first level were widely distributed across the urban cluster, covering peripheral areas such as Ya'an, Nanchong, and Dazhou, with clear spatial differentiation characteristics.

In 2017, the regional economic high-quality development exhibited a "single-core dominance, layer differentiation" pattern. Chengdu remained in the fifth level, forming the core of high-quality development. Chongqing and Mianyang were in the fourth level, creating secondary growth poles. Deyang rose from the second level to the third level, achieving a cross-level leap from a lower to a medium level. Seven cities, including Zigong, Luzhou, Leshan, Yibin, Meishan, Ziyang, and Ya'an, were concentrated in the second level, forming a medium-low-level aggregation belt in the southern part of Sichuan and the outskirts of Chengdu Plain. Five cities—Suining, Nanchong, Dazhou, Guang'an, and Neijiang—remained in the first level.

By 2023, the study area achieved a comprehensive optimization of the level structure and level leap, displaying characteristics of "one core leading, multi-level support, and medium-high level as the main body." Chengdu remained in the leading position in the fifth level. The fourth level grew to include three cities—Chongqing, Mianyang, and Deyang—forming a supporting pole for high-quality development. Deyang achieved a continuous leap from the second level in 2011 to the third level in 2017 and the fourth level in 2023. The third level expanded significantly, including Zigong, Yibin, Meishan, Ziyang, and Ya'an, indicating the formation of medium-level cities in the southern part of Sichuan and the Chengdu-Yaan corridor, with these cities having made the leap from the second to the third level. The second level now includes Luzhou, Leshan, Suining, Nanchong, Dazhou, Guang'an, and Neijiang. The first level has completely disappeared, marking the Chengdu-Chongqing Twin-City Economic Circle's full departure from the low-level development stage and its entry into the medium-low-level and above development stages.

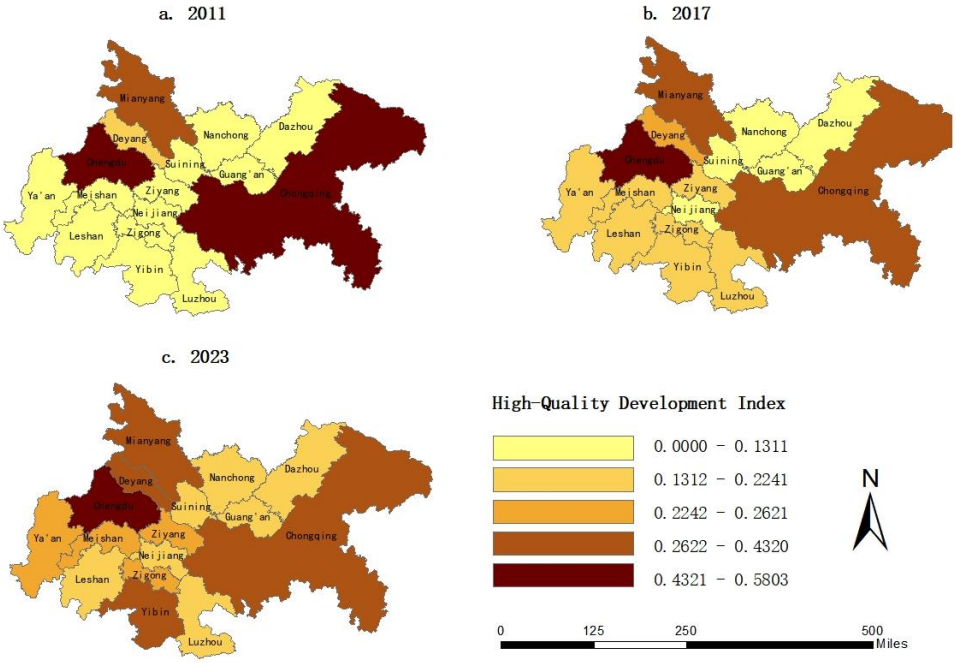

Figure 1. Changes in the Distribution of High-Quality Development Level Grades in the Chengdu-Chongqing Region from 2011 to 2023

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4.2. Social Network Analysis of High-Quality Development

Based on the above research methods, this paper calculates the gravity matrix using the modified gravity model and performs binarization. The social network of high-quality economic development in the Chengdu-Chongqing Twin-City Economic Circle is analyzed using UCINET.

4.2.1. Network Density Analysis

As shown in Table 2, during the period from 2011 to 2023, the number of economic connections in the Chengdu-Chongqing Twin-City Economic Circle's economic network remained largely unchanged. The number of connections in the three surveyed years were 48, 48, and 51, showing no significant increase in quantity. The changes in network density correspond to the changes in the number of connections, with the network densities for the three years being 0.2, 0.2, and 0.2125, showing very little fluctuation. The social network density of high-quality economic development reflects the degree of economic ties and cooperative exchanges between cities. Although there was no significant increase in the number of connections, the slight increase in network density in 2023 suggests that inter-city connections in the Chengdu-Chongqing Twin-City Economic Circle have increased. However, the overall low network density of high-quality economic development in the Chengdu-Chongqing region indicates that, despite progress in regional high-quality development, the economic connections between cities within the region remain insufficiently close.

Table 2. Network Density and Connectivity Analysis of High-Quality Development Spatial Association

Year	2011	2017	2023
Network Density	0.2	0.2	0.2125
Number of Connections	48	48	51

4.2.2. Network Centrality Analysis

As shown in Table 3, Chongqing's out-degree has consistently remained at a high level, with 7 in 2011, 6 in 2017, and returning to 7 in 2023, indicating that Chongqing's spillover effect in the regional economy has remained stable, and its economic driving role for surrounding cities remains significant. Chengdu's out-degree has fluctuated, rising from 3 in 2011 to 5 in 2017, but dropping back to 3 in 2023. This suggests that Chengdu's spillover effect strengthened during certain periods but weakened in later years, which may be related to economic transformation or external factors. Yibin's out-degree gradually increased from 3 in 2011 to 5 in 2023, showing that its spillover effect has been gradually enhancing, indicating that the city is playing an increasingly important role in the regional economy. Zigong's out-degree demonstrated a steady and gradual increase, rising from 4 in 2011 to 5 in 2017, and maintaining this level in 2023, indicating that Zigong's spillover effect has gradually strengthened. Cities like Ziyang, Dazhou, and Meishan have low out-degrees and small changes. For example, Ziyang's out-degree decreased from 5 to 2, Dazhou remained at 2, and Meishan remained at 1, indicating that these cities have weak spillover effects and have not effectively driven the economic development of other cities. These cities have limited economic influence in the Chengdu-Chongqing economic circle and remain on the periphery of the network.

As core cities, Chengdu and Chongqing have consistently had high in-degrees, demonstrating strong economic attraction and resource aggregation abilities. Especially Chengdu, whose in-degree was 15 in 2011 and remained at 14 in both 2017 and 2023, showing that Chengdu has a very strong ability to attract resources from other cities in the Chengdu-Chongqing region, maintaining a central position in high-quality economic development. Chongqing's in-degree was 7 in 2011, sharply rising to 12 in 2017, but dropping back to 8 in 2023, indicating

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fluctuations in its ability to attract external resources. Despite these fluctuations, Chongqing maintains high attraction and continues to exert significant influence on surrounding cities. Nanchong, Yibin, Ziyang, and others have seen their in-degrees gradually increase, indicating a growing ability to attract resources within the regional economy. Meanwhile, cities like Leshan and Ya'an have maintained relatively low in-degrees, suggesting they have weaker attraction and have not effectively drawn external resources.

Chongqing and Chengdu, as core cities in the Chengdu-Chongqing Twin-City Economic Circle, continue to play crucial intermediary roles in regional economic cooperation. Chongqing's intermediary centrality has risen from 45.117 in 2011 to 95.917 in 2023, indicating that its bridging role in high-quality economic development has strengthened year by year, maintaining its central position in the Chengdu-Chongqing economic circle. Chengdu's intermediary centrality reached its highest value of 66.833 in 2017 but decreased to 46.417 in 2023, showing that while Chengdu's intermediary role has fluctuated, it remains at a high level and continues to play an important guiding and coordinating role in the region. In contrast, some peripheral cities, such as Nanchong and Ziyang, saw an increase in their intermediary centrality in 2023, reaching 34.286 and 29.286, respectively, indicating that these cities' intermediary roles in the regional economy are gradually strengthening.

Table 3. Centrality of the High-Quality Development Spatial Association Network in the Chengdu-Chongqing Region

City	Out-Degree			In-Degree			Betweenness Centrality		
	2011	2017	2023	2011	2017	2023	2011	2017	2023
Chongqing	7	6	7	7	12	8	45.117	92.833	95.917
Chengdu	3	5	3	15	14	14	36	66.833	46.417
Zigong	4	5	5	3	3	2	10.417	16	1.25
Mianyang	2	3	3	2	2	1	0	9.333	0.333
Luzhou	4	3	3	2	2	2	7.717	12.833	7.286
Leshan	2	3	3	0	0	0	0	0	0
Yibin	3	3	5	1	1	3	1.4	0	3.083
Suining	3	3	3	2	1	1	2.167	0.833	0.286
Nanchong	3	2	3	2	4	5	2.167	10.167	34.286
Dazhou	2	2	2	1	1	1	0	0.833	0.286
Meishan	1	1	1	3	2	3	0	0	0
Ziyang	5	2	2	4	1	7	8.467	5.333	29.286
Guang'an	2	2	2	1	1	1	0	0.833	0.286
Neijiang	4	3	4	3	2	3	12.550	12.833	19.286
Deyang	2	3	4	2	2	0	0	0.333	0
Ya'an	1	2	1	0	0	0	0	0	0

4.2.3. Cohesion Subgroup Analysis

Using the CONCOR iterative convergence method, a clustering analysis was performed on the data from the three years, with a maximum cut depth of 2 and a concentration standard of 0.2. The 16 cities in the Chengdu-Chongqing region were divided into 4 subgroups. The cities in each subgroup changed over the years. In 2011, Subgroup 1 consisted of Chongqing, Zigong, and Ziyang; Subgroup 2 included Chengdu, Deyang, Leshan, Meishan, and Mianyang; Subgroup 3 included Luzhou, Neijiang, and Yibin; and Subgroup 4 included Suining, Nanchong, Dazhou, Guang'an, and Ya'an. In 2017, Subgroup 1 was composed of Chongqing and Chengdu; Subgroup

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2 consisted of Meishan and Deyang; Subgroup 3 included Neijiang, Luzhou, Zigong, and Yibin; and Subgroup 4 included Mianyang, Suining, Dazhou, Ziyang, Nanchong, Leshan, Guang'an, and Ya'an. In 2023, Subgroup 1 included Chongqing and Yibin; Subgroup 2 consisted of Chengdu, Mianyang, Deyang, and Leshan; Subgroup 3 included Luzhou, Suining, Guang'an, Dazhou, Zigong, and Neijiang; and Subgroup 4 included Nanchong, Ziyang, Meishan, and Ya'an.

Further analysis of the inter-subgroup connections yielded the density matrix for each subgroup. Specifically, when the density of a subgroup exceeds the overall network density, it is assigned a value of 1; otherwise, it is assigned a value of 0. Based on this, the resulting density and adjacency matrices are shown in Table 4. From the density matrix, it can be observed that in 2011, Subgroup 1's spillover effect was mainly reflected in its influence on Subgroups 2, 3, and 4; Subgroup 2's spillover effect was mostly confined within Subgroup 2, with no significant spillover to other subgroups; Subgroups 3 and 4 mainly had spillover effects on Subgroup 1. In 2017, Subgroup 1's spillover effect mainly extended to Subgroups 2, 3, and 4; Subgroups 2 and 4's spillover effects were mainly directed towards Subgroup 1; and Subgroup 3's spillover effect was mainly confined within Subgroup 3 and to Subgroup 1. In 2023, Subgroup 1's spillover effect was mainly directed towards Subgroups 3 and 4; Subgroup 2's spillover effect was mainly internal to Subgroup 2; and Subgroups 3 and 4's spillover effects were mainly directed towards Subgroups 1 and 2. The adjacency matrix provides a clearer reflection of the economic links between subgroups. The diagonal values of the adjacency matrix are mostly 0, with 1 primarily found off-diagonal, indicating that inter-subgroup exchanges are more frequent than intra-subgroup exchanges. Throughout the study period, Subgroup 1 consistently maintained economic links with Subgroups 3 and 4; Subgroup 2 had weak connections with Subgroup 3; Subgroup 3 consistently maintained economic links with Subgroup 1, but had weak links with Subgroup 4; and Subgroup 4 had economic links with Subgroup 1, but weak links with Subgroup 3.

Table 4. Density Matrix and Adjacency Matrix of the High-Quality Development Spatial Association Network

Density Matrix					Adjacency Matrix			
2011	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Subgroup 1	0	0.267	0.667	0.4	0	1	1	1
Subgroup 2	0	0.5	0	0	0	1	0	0
Subgroup 3	0.889	0.2	0	0	1	0	0	0
Subgroup 4	0.4	0.2	0	0	1	0	0	0
2017	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Subgroup 1	0	0.5	0.25	0.438	0	1	1	1
Subgroup 2	0.5	0	0	0.125	1	0	0	0
Subgroup 3	1	0	0.5	0	1	0	1	0
Subgroup 4	1	0.125	0	0.018	1	0	0	0
2023	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Subgroup 1	0	0.125	0.667	0.375	0	0	1	1
Subgroup 2	0	0.25	0	0.625	0	1	0	1
Subgroup 3	0.75	0.25	0.067	0.083	1	1	0	0
Subgroup 4	0.25	0.313	0	0	1	1	0	0

5. Conclusion and Discussion

This study systematically analyzed the spatial structure and dynamic evolution of high-quality economic development in the Chengdu-Chongqing Twin-City Economic Circle. Using the modified gravity model and social network analysis, the study explored the economic

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connections between cities in the region and their changing trends, revealing the main characteristics of high-quality economic development in the region during 2011, 2017, and 2023.

The research results indicate that the Chengdu-Chongqing Twin-City Economic Circle exhibits clear urban polarization characteristics. Chengdu and Chongqing, as core cities, have consistently dominated regional economic development. Although the high-quality economic development levels of cities in the region have gradually improved, disparities between cities still exist. In 2011, the Chengdu-Chongqing region displayed a significant "dual-core polarization" spatial pattern, with Chengdu and Chongqing in the fifth level of high-quality economic development, while other cities were at lower levels. In 2017, regional economic development showed a "single-core dominance with layer differentiation" pattern. Chengdu formed the core of high-quality development, while Chongqing and Mianyang were secondary growth poles. By 2023, the regional economic structure had been optimized, with Chengdu remaining in the fifth level. Other cities, such as Deyang and Yibin, also made significant leaps, marking a new stage in the high-quality development of the Chengdu-Chongqing Twin-City Economic Circle.

In terms of social network analysis, although the economic connections in the Chengdu-Chongqing region did not significantly increase in quantity, the network density slightly rose, indicating that economic connections between cities have strengthened. As core cities, Chongqing and Chengdu's economic spillover effects have remained significant, with a stable and sustained economic radiation effect on surrounding cities. However, the economic attraction of some peripheral cities is weaker, and their central roles in the high-quality economic development network are relatively small. Cities such as Ziyang and Dazhou have limited influence in the regional economy and remain on the periphery of the network.

The findings of this study suggest that, despite the positive progress made in high-quality economic development within the Chengdu-Chongqing Twin-City Economic Circle, further strengthening of economic connections between cities is required. To further promote regional integration and balanced development, it is recommended to enhance government intervention at key urban nodes, foster closer economic ties between cities, and reduce the development gaps between them. Additionally, the government should focus on optimizing resource allocation, promoting innovation-driven development, and strongly supporting green transformation to achieve sustainable, high-quality regional economic development.

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