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A Comparative Study of the Network Structure of the Yangtze River Delta Smart City Cluster Before and After Anhui's Integration (Postprint)

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Date: 2023-10-08T00:00:00+00:00

Abstract

This study employs social network analysis methods, utilizing economic linkage data from 2010 to 2019, to investigate changes in the morphology and internal characteristics of the Yangtze River Delta smart city cluster before and after Anhui Province's inclusion. The findings reveal that following Anhui Province's inclusion, the economic network structure of the Yangtze River Delta smart city cluster underwent significant transformations: the disparity in economic linkages narrowed, the compactness of the smart city cluster and the clustering of internal nodes were alleviated, resource flow accessibility improved, some small and medium-sized cities assumed more active roles, and disparities in the vertical development of the urban agglomeration were mitigated.

Full Text

A Comparative Study on the Network Structure of the Yangtze River Delta Smart City Cluster Before and After Anhui's Integration

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Abstract: This study employs social network analysis methods and utilizes economic connection data from 2010-2019 to investigate the structural and internal characteristic changes of the Yangtze River Delta smart city cluster before and

after Anhui Province' s integration. The findings reveal that following Anhui' s inclusion, the economic network structure of the Yangtze River Delta smart city cluster underwent significant changes: the gap in economic connections narrowed, both the compactness of the smart city cluster and internal node agglomeration were alleviated, resource flow accessibility improved, certain small and medium-sized cities assumed more active roles, and the disparities in vertical development across the city cluster were mitigated.

Keywords: Smart city cluster; Economic connections; Spatial structure; Social network analysis; Gravity model

1. Research Methods

1.1 Research Scope

The research scope encompasses the constituent members of the Yangtze River Delta urban agglomeration in 2019, with city lists by province shown in Table 1 . To facilitate comparative analysis of network structural changes before and after Anhui' s integration, this study establishes two network configurations based on the nationally defined scope and timeline for the Yangtze River Delta smart city cluster: Network 1 comprises 27 Yangtze River Delta cities including Anhui' s smart cities, while Network 2 comprises 19 cities excluding Anhui. Panel data spanning 2010-2019 for various indicators across each city serve as the dataset for this study.

1.2 Social Network Analysis Method

First, to measure the intensity of economic connections between any two smart cities in Networks 1 and 2, this study adopts the gravity model employed by Wang Dezhong et al. [?] in their research on economic connections between Shanghai and smart cities such as Suzhou, Wuxi, and Changzhou:

$$R_{ij} = \frac{\sqrt{P_i V_i \cdot P_j V_j}}{D_{ij}^2}$$

where P_i and P_j represent the registered population of smart cities i and j ; V_i and V_j represent the gross industrial output value of smart cities i and j ; and D_{ij} is the spatial distance between smart cities i and j . Considering the directional nature of economic connections between smart cities—where the economic connection from smart city i to j differs from that of j to i —this study proposes using parameter k to capture this characteristic. Drawing upon the modified parameters for inter-city gravity models from Li Xiang and Shao Xuanxuan [?, ?], the gravity model for calculating the economic connection from smart city i to smart city j is formulated as:

$$R_{ij} = K_{ij} \frac{\sqrt{P_i G_i \cdot P_j G_j}}{D_{ij}^2}$$

where K_{ij} represents the influence degree of smart city i on R_{ij} ; P_i and P_j denote the permanent resident populations of smart cities i and j ; G_i and G_j denote the regional GDP of cities i and j , respectively; and D_{ij} is the shortest highway distance between smart cities i and j .

2. Empirical Analysis

2.1 Inter-City Economic Connections

Through formula (1), twenty economic connection matrices for smart cities in both Network 1 and Network 2 from 2010–2019 were obtained. After basic processing, relevant data on economic connections within the Yangtze River Delta smart city cluster were derived, with 2010–2013 data representing Network 1 and 2014–2019 data representing Network 2, as shown in Table 2 .

During 2010–2019, the economic network density of both Network 1 and Network 2 demonstrated large base values with stable growth. Due to the expanded scale of smart cities, Network 1 consistently exhibited lower compactness than Network 2. In 2014, when Anhui Province joined the Yangtze River Delta smart city cluster, it rapidly established close economic connections with other smart cities, resulting in a significant and sustained increase in network density. This indicates that Anhui' s integration exerted a positive effect on the density structure of the Yangtze River Delta. Additionally, the study finds that when network density reaches high levels, the transaction costs required to build close economic connections become relatively higher, thereby inhibiting the efficient use of production factors. Consequently, identifying and maintaining an appropriate smart city scale and network density can promote the coordinated and sustainable development of smart city cluster networks.

2.2 Network Structure Analysis

2.2.1 Network Scale and Density In social network analysis, network scale is primarily measured by the number of nodes within the network. More nodes signify a larger network scale, implying a broader scope of sources and transmission of economic elements, more complex structures, and more pronounced local agglomeration effects [?, ?].

2.2.2 Average Path Length Analysis Network average path length refers to the shortest connection path requiring the fewest intermediate nodes between nodes i and j . In smart city cluster networks, shorter average path lengths indicate lower connection costs and more efficient factor exchange.

As illustrated in Figure 2 [Figure 2: see original paper], the average path lengths between smart cities in Networks 1 and 2 ranged between 1 and 1.1 during 2010–2019. Only a small fraction of smart city pairs lacked direct connections, with nearly all cities able to facilitate economic factor flows through just 1–1.098 intermediate cities on average. The average path length decreased noticeably year by year, while the total volume of economic connections in the Yangtze River Delta maintained growth throughout the decade.

The reduction in Network 1's average path length far exceeded that of Network 2, particularly after Anhui's formal integration into the Yangtze River Delta smart city cluster in 2014, when an obvious inflection point accelerated the declining trend. This enhancement in compactness and transmissibility reduced resource transmission loss rates.

In 2014, following Anhui's integration into the Yangtze River Delta smart city cluster, the expanded smart city base caused a sharp decline in the average economic connection value, as newly added cities initially lacked strong economic ties with existing members. Prior to 2014, the standard deviation for Network 2 ranged between 135–188, indicating large dispersion in economic connection volumes, significant data fluctuations, and high differentiation in inter-city economic connection intensity—a gap that was widening at an accelerating pace. After Anhui's smart cities joined, the standard deviation dropped significantly, slowing the differentiation in economic connection intensities between cities and enabling steady development of the internal network structure, which aligns with the objectives of Yangtze River Delta regional integration.

3. Conclusions

As a model region for smart city development, the Yangtze River Delta has fostered economic integration within its smart city cluster through regional big data. Based on panel data from 27 smart cities in the Yangtze River Delta region from 2010–2019 and employing social network analysis tools, this study draws the following conclusions:

1. The economic network of the Yangtze River Delta smart city cluster has reached a relatively mature stage, characterized by dense and complex network structures, high factor mobility, and stable growth. However, the internal economic network exhibits overall imbalance, with peripheral smart cities remaining marginalized, external economic radiation decreasing year by year, and regional invisible barriers increasing.
2. Anhui's integration has positively impacted the overall network of the Yangtze River Delta smart city cluster, significantly increasing the total volume of economic connections, reducing differentiation in economic connections between smart city nodes, enhancing overall economic exchange activity, and improving the accessibility of internal capital, trade, and

other factor flows.

3. Anhui's integration has alleviated node agglomeration phenomena within the smart city cluster, mitigated the previous high concentration, narrowed the significant core-periphery disparities, optimized the internal structure of the Yangtze River Delta smart city cluster, and promoted regional integrated development.

Network centrality describes the overall centrality of a network, with two types: in-degree centrality and out-degree centrality. In-degree centrality represents the degree to which the smart city cluster as a whole introduces economic connections from external sources, while out-degree centrality represents the cluster's radiating influence on other regions.

In-degree centrality. The in-degree centrality of both Network 1 and Network 2 fluctuated consistently during the decade, with Network 2's in-degree centrality always higher than Network 1's. This indicates that the Yangtze River Delta smart city cluster without Anhui's smart cities demonstrated stronger economic attraction to external smart cities. After Anhui's smart cities were incorporated, the cluster's capacity to introduce external economies declined, but the total volume of economic connections increased significantly, suggesting that economic factors flowed more fully within the internal network. This optimized network accessibility and created greater economic value output.

Out-degree centrality. From 2010-2019, Network 1's out-degree centrality remained consistently lower than Network 2's, indicating that the Yangtze River Delta smart city cluster without Anhui exerted stronger economic radiation effects on its surroundings. After 2014, Network 1's out-degree centrality stabilized. The underlying reason may be that established core smart cities in the Yangtze River Delta cluster have been advancing industrial transfer processes in recent years, with small and medium-sized smart cities within the cluster—such as Ma'anshan, Xuancheng, and Chizhou in the Wanjiang smart city belt—gradually assuming the transfer of primary and secondary industries from the core Jiangsu-Zhejiang-Shanghai region. This internal transfer incurs lower costs and achieves higher efficiency than connections with smart cities outside the network.

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(Editor: Zhang Xiaojing)

Note: Figure translations are in progress. See original paper for figures.

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