Analysis of China's Provincial Economic Link Network Based on PageRank Algorithm

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Abstract. Under the new dual-circulation development paradigm, traditional regional economic evaluation systems struggle to capture dynamic interactions between provinces. This study integrates complex network theory into regional economic research by constructing an inter-provincial economic network encompassing trade, investment, and population dimensions. Using the PageRank algorithm to assess node importance, the results reveal that the Yangtze River Delta dominates the trade network, while the investment network exhibits cross-regional characteristics driven by policy initiatives. In the population network, Ningxia and Qinghai serve as pivotal hubs. Between 2012 and 2023, the economic network evolved from a single-core structure in eastern regions to a multi-polar collaborative development model, with Jiangsu and Zhejiang provinces becoming primary cores. Meanwhile, central and western regions have shown gradual improvement. This research demonstrates enhanced regional resource allocation efficiency, providing insights for coordinated development processes while addressing previous limitations in dynamic mechanism analysis.

Keywords: PageRank algorithm, gravity model, principal component analysis, economic link network, regional economy.

1. Introduction

On April 30,2025, Presiden Xi emphasized at the symposium on socioeconomic development during the 15th Five-Year Plan period: "We must unwaveringly advance our domestic affairs and expand high-level opening-up. Through multiple measures to stabilize employment, enterprises, markets, and expectations, we will effectively consolidate the economic foundation, accelerate the establishment of a new development paradigm, and comprehensively promote high-quality growth. Under the dual-circulation development framework, traditional GDP-based regional economic evaluation systems struggle to capture the dynamic interactions of trade flows and capital flows between provinces. Therefore, accurately mapping the structural characteristics of interprovincial economic networks and analyzing their developmental trajectories and underlying causes are crucial for optimizing resource allocation and enhancing regional coordination [1-4].

Scholars have utilized complex network theory and social network analysis methods to conduct comprehensive research on China's regional economic networks. In terms of trade networks, Leng Bingrong (2011) constructed an urban link network using an improved gravity model, indicating that Chinese cities can be divided into northern urban areas, Yangtze River urban areas, and southern urban areas, with a "three-pole multi-core" spatial structure gradually taking shape. The direction of network connections is primarily concentrated in the Bohai Rim, Yangtze River Delta, and Pearl River Delta regions [5]. Jiang Xuemei (2021) analyzed the global intermediate goods trade network using the PageRank algorithm, concluding that developed economies dominate in global high-tech trade networks while developing economies have risen in status but need to enhance their participation [6]. In investment network research, Lian Xiaomei (2024) demonstrated through social network analysis that the overall density of economic linkages in Northeast China exhibited a pattern of initial increase followed by decline, with provincial administrative divisions significantly constraining economic connections. Cities within the same province showed closer ties, presenting a "high in the south, low in the north" distribution pattern [7]. Bian Yitang et al. (2011) established a generalized network and expansion model for stock market investments, revealing that networks possess scale-free and small-world characteristics, with node degree distributions following bidirectional power-law patterns [8]. Regarding regional economic linkages and disparities, Luo Pengwei (2021) using Northwest China as a case study found that cities like Xi' an and Urumqi serve as regional economic growth poles, with spatially uneven distribution characteristics in economic linkage intensity that decreases from east to west [9].

Current research predominantly focuses on specific urban clusters such as Northwest China, Northeast China, and the Haixi region, or examines economic dimensions like trade and investment in isolation. There remains a significant gap in multidimensional studies of interprovincial economic networks across China, making it challenging to fully grasp network complexity. Moreover, most existing studies rely on static cross-sectional analyses, lacking exploration of how economic network structures evolve over time and the driving mechanisms behind these changes.

Therefore, the significance of this study lies in integrating complex network theory with regional economic research to establish a multi-dimensional interprovincial economic network analysis framework. This approach breaks through the limitations of traditional single-dimensional research, thereby enriching regional economic theory. By analyzing the structural characteristics of interprovincial economic networks, we identify key nodes and vulnerable links within the network, thus providing scientific basis for formulating regional economic policies under strategies such as the Belt and Road Initiative and the Beijing-Tianjin-Hebei coordinated development.

This study utilizes interprovincial trade data, investment data, and population data to analyze node importance through the PageRank algorithm. In terms of research scope, the paper breaks away from existing studies that focus solely on economic dimensions or regional constraints, establishing a comprehensive framework for analyzing the interprovincial economic network that encompasses trade, investment, and population. Methodologically, the PageRank algorithm is employed to develop a dynamic resilience index system, enabling multi-dimensional evaluation of structural characteristics and developmental patterns in interprovincial economic networks. Regarding mechanism elucidation, the study thoroughly explores the formation mechanisms behind differences in economic network resilience among provinces, conducting detailed analyses from perspectives such as geographical location, industrial structure, and policy conditions. This approach addresses gaps in current research regarding the interpretation of regional differentiation mechanisms.

2. Research Methods and Data

2.1. Data presentation

2.1.1. Trade networks

Regarding trade networks, this paper selects the GDP of 30 provinces in China from ——2012 to 2023 and the spatial distances between provinces. Domestic scholars predominantly use classical gravity models, primarily modifying the gravity model through three aspects: urban quality, inter-city distance, and gravity coefficient to measure the intensity of urban economic linkages [10-18]. This study comprehensively adopts the gravity model used by W. Isard and Zhang Hongmei (2018) for calculation [19-20], which assumes that the trade flow between two regions is proportional to their respective economic scales and inversely proportional to the distance between regions. The specific formula is as follows:

$$T_{ij}=k\cdot\frac{GDP_i\cdot GDP_j}{D_{ij}}$$

Among $T_{ij} GDP_i GDP_j D_{ij}$ them, represents the theoretical trade flow between province i and province j, where is the GDP of province i and province j respectively, is the geographical distance between province i and j, and k is a model constant. The GDP data of each province are sourced from the Bureau of Statistics. The inter-provincial distances are calculated using the distance between provincial capitals, which was measured by referencing Leng Bingrong's (2011) method [21]. Specifically, the comprehensive transportation distance between cities is calculated by considering the transportation network composed of railways, expressways, and some highways. During the calculation process, key factors were considered: the dominant role of highways in passenger and freight turnover, the predominance of short-distance transportation by road with similar railway and highway distances, and the factor of railway freight costs in long-distance transportation. Ultimately, the shortest distance between road and railway was selected as the comprehensive transportation distance. The above data are sourced from the China Statistical Yearbook.

2.1.2. Investment network

This study analyzes investment event data from —— 2012 to 2023. Building on the methodology developed by Bian Yitang (2011) and colleagues, we construct an investment network by treating stock market investors and listed companies as network nodes, where ownership relationships between them serve as edge connections. The study defines investor investment capacity and stock price returns as characteristic attributes of these nodes. The algorithmic framework involves three key components: defining node scales in the stock market network, determining intrinsic attribute distributions within nodes, and establishing edge connection probabilities. Through simulation experiments, we systematically analyze statistical parameters including network degree distribution, cluster coefficients, average path lengths, and network stability. Building upon this methodology, we implement simplified procedures: first, matching investors and financiers by province to aggregate inter-provincial investment data; second, calculating edge weights; and finally, constructing an investment matrix. Edge weights are defined by the formula where i represents investor provinces and j denotes financier provinces. All data are sourced from Qingke Peda Data's institutional investment event database.

$$The\ side\ weight\ _{i\to j}=\frac{Investment\ amount_{i\to j}}{Total\ outward\ investment_i}$$

2.1.3. Population networks

Using the permanent resident population and natural population growth rates of 30 Chinese provinces from 2012 to 2023 as edge weights, we constructed a network matrix. These data were sourced from the Bureau of Statistics. The "permanent population of Region i / permanent population of Region j" section reflects regional population size comparisons, indicating the relative scale of populations between two areas. If Region i has a larger permanent population than Region j, this ratio will be greater than 1, which increases subsequent calculation results; conversely, it decreases them. This difference demonstrates the fundamental impact of population size disparities on the strength of regional connections. The "|natural population growth rate of Region i-natural population growth rate of Region j|" section employs absolute values to calculate the difference in natural population growth rates between regions. A larger absolute value indicates a greater disparity in population growth trends between the two areas.

$$Edge\ weighting=\frac{The\ permanent\ population\ of\ the\ region\ i}{The\ permanent\ population\ of\ the\ region\ j}\times$$
$$|Natural\ population\ growth\ rate\ of\ region\ i\text{-}natural\ population\ growth\ rate\ of\ region\ j|$$

2.2. PageRank algorithm

2.2.1. PageRank algorithm implementation logic

The PageRank model in this paper mainly converts the adjacency matrix of economic link network into a probability transition matrix, and then calculates the importance score of each node through iterative calculation. The specific process is as follows:

(1) Adjacency matrix normalization: Each element in the original adjacency matrix is divided by P_{ij} the sum of the corresponding row to obtain the probability transition matrix P, where represents the probability of transferring from node i to node j. The process formula is as follows:

$$P_{ij}=\frac{A_{ij}}{\sum_{k=1}^{n} A_{ik}}$$

Where A is the original adjacency matrix and n is the number of nodes (30 provinces). If the sum of a row is 0, it is treated as a uniform distribution probability.

(2) Iterative calculation of PageRank value: introduce damping factor d=0.85 to simulate the "random walk" behavior in economic links and avoid the emergence of "dead ends" in the network. The iterative formula is:

$$(t) PR(t+1)=(1-d)\cdot\frac{1}{n}+d\cdot P^T\cdot PR$$

Where PRP^T(t) is the PageRank vector of the t-th iteration, and is the transpose of the transition matrix. The algorithm converges when the change of PR value between two adjacent iterations is less than the threshold.

2.2.2. Algorithm Convergence and Damping Factor Interpretation

(1) Convergence. The code is forced to terminate after 100 iterations $\|PR(t+1)-PR(t)\|<tol$or meet the condition in advance to ensure that the PR value is stable near the unique solution.

(2) Damping Factor (d). The value of 0.85 indicates that in the economic network, users have an 85% probability of moving along existing connections and a 15% probability of randomly jumping to any province. This setting aligns with real-world economic behavior —— where entities not only rely on established connections but may also make random new connections due to policy changes or market fluctuations.

2.2.3. PageRank algorithm application

(1) Combine logic with data

Based on data from the gravity model using trade networks, the edge weight formulas derived from investment networks and population networks are correlated with population size and growth rate indicators. By inputting adjacency matrices from three distinct network types into the PageRank algorithm, this approach bridges the gap between "raw economic link data" and "assessing node importance," addressing the limitation of traditional studies that consider only single factors. The PageRank model enables evaluation of radiation effects within node networks, mediating degrees, and core degree analysis for provinces across trade, investment, and population networks. This methodology facilitates comprehensive analysis of these diverse network types.

(2) Specific calculation process

Taking the trade network as an example, we first use the inter-provincial $T_{ij}P_{ij}=\frac{A_{ij}}{\sum_{k=1}^{n}A_{ik}}PR(t+1)=(1-d)\cdot\frac{1}{n}+d\cdot P^T\cdot PR$trade flow matrix calculated by the gravity model as the initial adjacency matrix A, where the elements represent the intensity of trade links between provinces i and j. Next, standardize A using the formula to obtain the probability transition matrix P of the trade network, where represents the probability of trade link shifting from province i to province j. We then define a damping factor d=0.85 and calculate each province's PageRank value through iteration formula (t). If province i has strong trade links with multiple high-importance provinces, its PR value will be significantly elevated, indicating that province i holds a crucial position in the trade network. Finally, we repeat the above process for investment networks and population networks to obtain node importance scores for each type of network. The overall PR value of provinces within the entire economic network is then calculated through comprehensive weighting.

(3) Practical application

By comparing the PR values of provinces in trade, investment, and population networks across different dimensions, we can identify core provinces from various perspectives, providing quantitative foundations for subsequent network matrix analysis. Through computational analysis of PR value trends from 2012 to 2023, we visually demonstrate the evolution of provincial importance, offering data support for the subsequent conclusion of "transitioning from a single-core structure to multi-polar coordination" in regional development. When combined with PR values and strategic timelines, this approach quantifies the impact of strategies on interprovincial economic linkages, providing empirical support for the scientific basis of policy formulation proposed in this study.

3. Empirical analysis of economic linkages

3.1. Network matrix analysis

3.1.1. Trade networks

As shown in Table 1, the Yangtze River Delta region holds an absolute dominant position in trade networks. Jiangsu undoubtedly serves as the most central hub, maintaining strong trade network relationships with Zhejiang, Anhui, Shanghai, and Shandong. Notably, its trade relationship with Zhejiang is the strongest, reaching 874,201,236.2. Shanghai, as an international financial center, also maintains frequent trade exchanges with Zhejiang and Jiangsu, indicating deep industrial collaboration between Shanghai and the Zhejiang-Suzhou regions. The trade connections between Jiangsu and Shandong are equally significant, ranking fifth in intensity. This demonstrates Shandong's crucial role as a pivotal link in connecting the Yangtze River Delta with northern regions. This trade network exhibits both detailed regional industrial specialization and collaborative cooperation among provinces leveraging their resource advantages, demonstrating strong economic synergy [22-23].

Table 1. Top 5 Provincial Pairs with the Strongest Trade Network Ties in 2023

Province 1	Province 2	Intensity of Population Network Ties
Jiangsu	Zhejiang	87420123.624942
Jiangsu	Anhui	76263044.9353478
Shanghai	Zhejiang	47875897.8142866
Shanghai	Jiangsu	44925869.122697
Jiangsu	Shandong	44284631.8318554

The three diagrams below present trade network matrix data through bubble charts, visualizing inter-provincial trade relationships in a dot matrix format where dot sizes indicate connection strength. All diagrams demonstrate dense dot distributions centered around Yangtze River Delta provinces, with the core area representing trade linkages between Jiangsu, Zhejiang, and Shanghai, highlighting the region's tightly-knit internal trade network. Jiangsu occupies a pivotal position, leveraging its manufacturing and logistics advantages to coordinate trade across the Yangtze River Delta and neighboring regions. Comparative analysis reveals a contraction trend in both the number and coverage of core nodes, with trade resources increasingly concentrated along optimal core pathways while non-core cross-regional links diminish in prominence. This visualization demonstrates the Matthew effect of "the strong getting stronger" within the trade network. Collectively, these results reveal three defining characteristics: core agglomeration in the Yangtze River Delta, hub-driven development by Jiangsu, and significant hierarchical differentiation. The central cluster maintains tight coordination, while peripheral regions gradually concentrate resources toward core pathways over time.

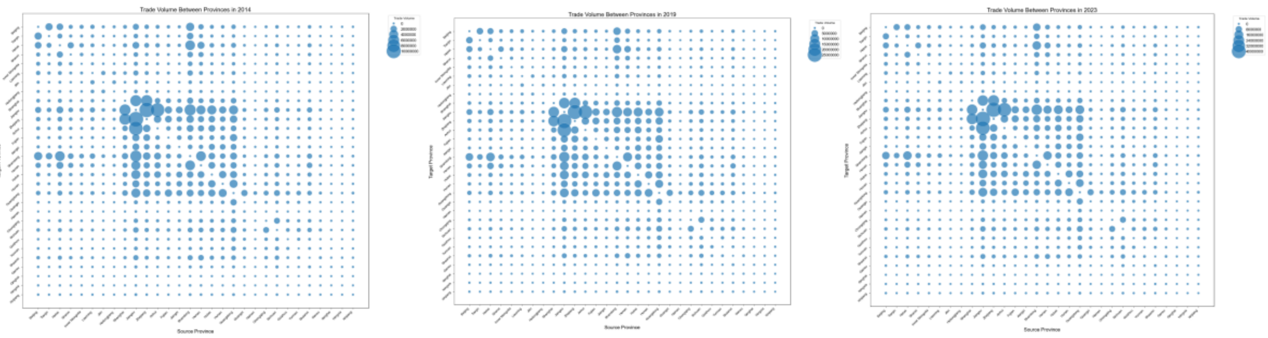

Figure 1. Trade network bubble plot for 2014,2019 and 2023

3.1.2. Investment network

As shown in Table 2, the investment network is dominated by non-traditional economic powerhouses and exhibits distinct cross-regional investment characteristics. The Qinghai-Guangxi corridor serves as the absolute core of this network. As the most intensive investment portfolio, the connection between Qinghai and Guangxi reflects the impetus from strategies like the New Western Land-Sea Corridor. The complementary advantages of Qinghai's resource-based industries and Guangxi's port logistics form a synergy, with investment flows likely concentrated in energy transportation and cross-border trade infrastructure sectors. This clearly demonstrates that investment behavior and trade flows follow fundamentally different internal logic. Investment flows typically favor regions endowed with policy dividends or those sharing resource complementarity with investors, rather than being solely tied to economic scale size.

Table 2. Top 5 Provincial Pairs with the Strongest Investment Network Ties in 2023

Province 1	Province 2	Intensity of Investment Network Ties
Qinghai	Guangxi	1.000000
Hainan	Hebei	0.569223
Yunnan	Shanghai	0.443044
Guizhou	Sichuan	0.202200
Hunan	Zhejiang	0.170587

The three visualizations below present investment network bubble diagrams from 2014,2019, and 2023 respectively. Unlike trade networks, investment networks are characterized by discrete bubbles and cross-regional distribution, reflecting the cross-domain and discontinuous nature of investment activities. Bubbles representing high-intensity investment clusters exhibit expansive "east-west and north-south" distributions, indicating greater emphasis on cross-domain complementarity in policies and resources. Policy analysis reveals that the high-intensity investment link between Qinghai and Guangxi aligns with strategies such as the New Western Land-Sea Corridor and coordinated regional development. These policies have facilitated investment collaboration between Qinghai—a resource-rich province—and Guangxi, a corridor hub, enhancing capital flows in energy transportation and cross-border trade infrastructure. Collectively, these three visualization diagrams clearly demonstrate a fragmented, policy-driven, and cross-domain mismatched investment landscape, showcasing the achievements of regional coordinated development strategies.

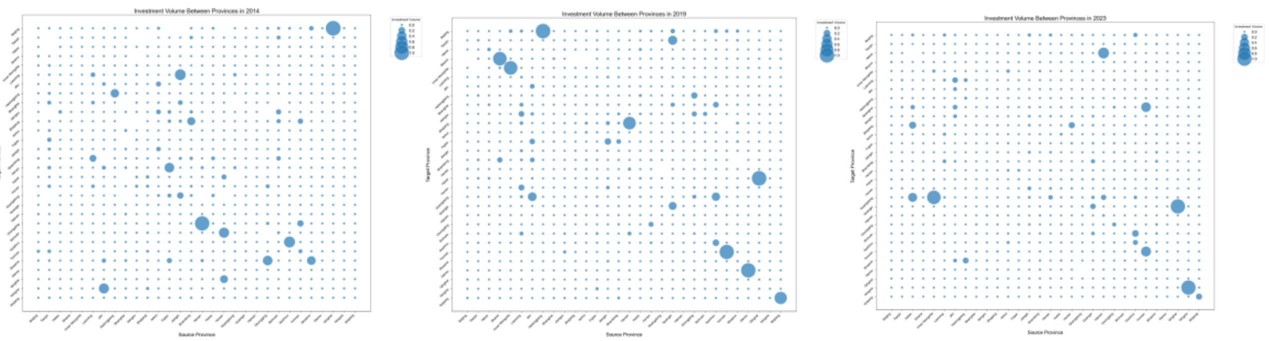

Figure 2. Investment network bubble plot for 2014, 2019 and 2023

3.1.3. Population networks

As shown in Table 3, the population network demonstrates a core association pattern centered on Ningxia and Qinghai, with cross-regional interactions between eastern and western provinces, highlighting trans-regional connections driven by population mobility. The top three high-intensity relationships all revolve around Ningxia, with relationship strength exceeding 72, indicating its role as a regional population mobility hub. The Sichuan-Qinghai and Shandong-Qinghai relationships rank fourth and fifth respectively in terms of intensity, suggesting Qinghai serves as a secondary hub for population movement. Both Ningxia and Qinghai have been instrumental in driving population interactions between eastern provinces like Shandong and Jiangsu through policies such as ecological migration and poverty alleviation collaboration. Unlike trade and investment networks that focus on core sectors, this "strong regional hub" structure reflects the unique nature of population mobility being driven by "policy orientation and livelihood need." Such a "livelihood-oriented" network framework provides visual insights for understanding regional population coordination and formulating employment and poverty alleviation policies.

Table 3. Top 5 Provincial Pairs with the Strongest Population Network Ties in 2023

Province 1	Province 2	Intensity of Population Network Ties
Shandong	Ningxia	78.305276
Sichuan	Ningxia	75.756354
Jiangsu	Ningxia	72.688624
Sichuan	Qinghai	67.960929
Shandong	Qinghai	66.008956

The three visualizations below demonstrate the population network matrix. The clustered bubbles associated with Ningxia further confirm its role as a core hub for cross-regional population mobility. The dense clusters of Ningxia, Qinghai, and eastern/western provinces vividly illustrate policy-driven "cross-regional migration". Manufacturing in Shandong and Jiangsu, energy production in Ningxia, and salt lake industries in Qinghai create cross-regional labor supply-demand alignment: industrial upgrades in eastern provinces generate labor export demands, while expanding specialty industries in western regions create employment gaps, driving population movement.

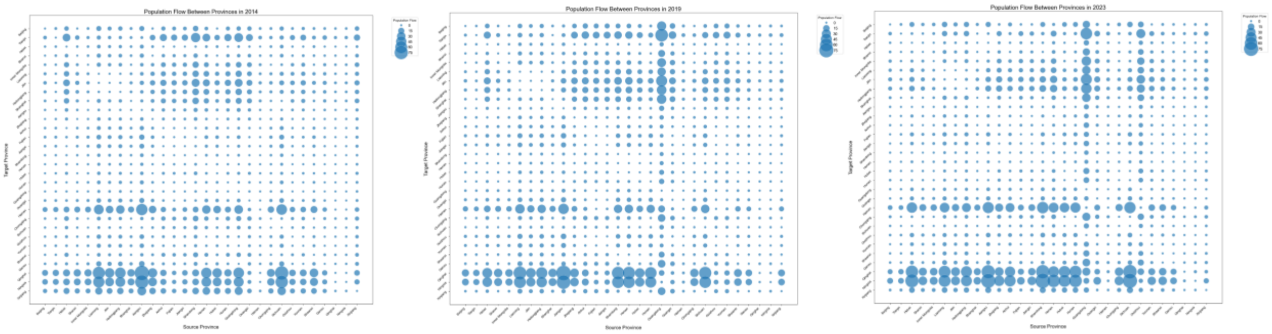

Figure 3. Population bubble in 2014, 2019 and 2023

3.2. Pagerank analysis

The three diagrams below are the inter-provincial network topologies calculated through the PageRank algorithm for 2014,2019, and 2023. For the 2014 provincial network topology, its core nodes are mainly eastern coastal provinces such as Jiangsu, Zhejiang, Shanghai, and Guangdong, which exert significant influence and radiating driving effects in the economic network. The eastern coastal regions enjoy relatively prosperous economies, solid industrial foundations, and highly convenient transportation—these constitute the core areas of China's economic development. Secondary core nodes include provinces like Shandong, Henan, and Hebei, which serve as bridgeheads in regional economies, connecting key central areas with other provinces. The peripheral nodes are western provinces such as Ningxia, Inner Mongolia, Gansu, and Qinghai, which may be related to the lower economic development levels in western regions at that time and the lack of close economic exchanges and cooperation with eastern areas.

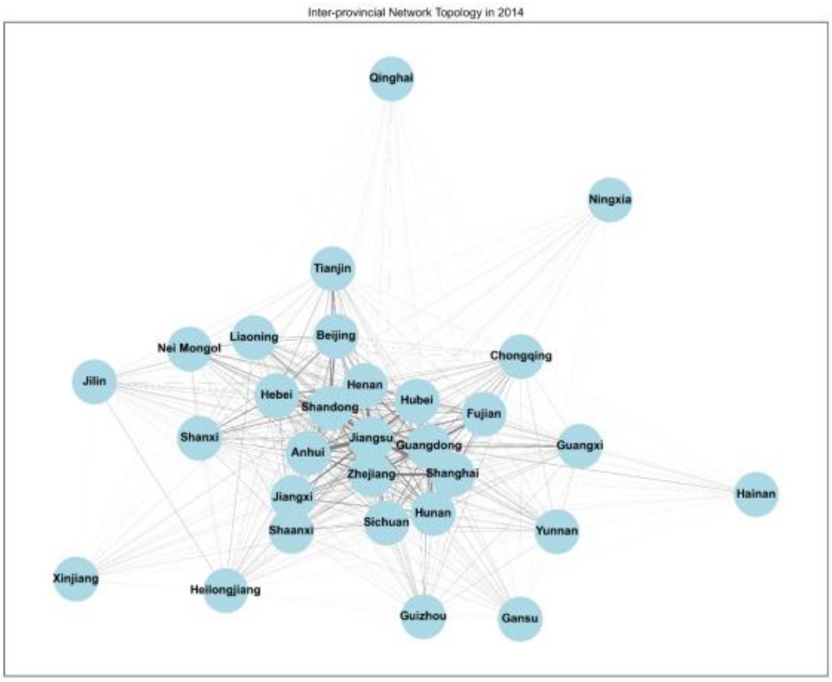

Figure 4. Interprovincial network topology in 2014

Compared to 2014, Beijing and Tianjin saw their economic prominence rise in 2019, driven by the coordinated development of the Beijing-Tianjin-Hebei region, which has solidified their central role in China's economy. Central provinces like Sichuan, Hubei, and Hunan have strengthened their connections with core economic hubs as secondary nodes. Under the implementation of the Central China Rise strategy, these regions experienced rapid economic growth, significantly enhancing their strategic importance. Overall, the 2019 economic network structure became more complex, with collaborative development effects from urban clusters such as the Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta becoming increasingly evident, driving economic growth in surrounding areas.

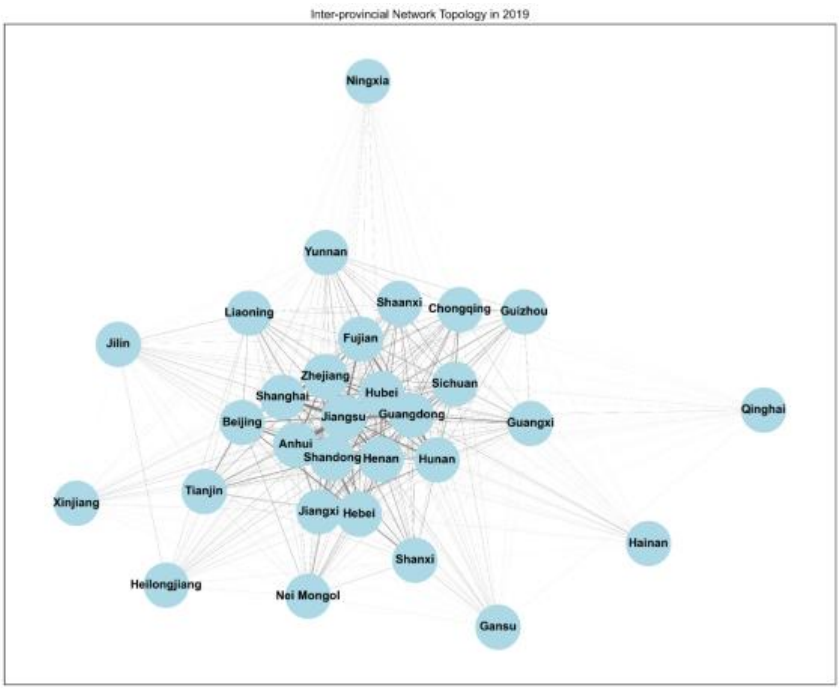

Figure 5. Interprovincial network topology in 2019

In 2023, the status of Jiangsu, Zhejiang, Shanghai, and Guangdong remained stable, while Fujian's position saw significant improvement, which is related to the development of the Guangdong-Hong

Kong-Macao Greater Bay Area and the Western Taiwan Strait Economic Zone. The secondary core status became more prominent, with western provinces such as Shaanxi and Chongqing entering the ranks of secondary core nodes. Western provinces including Ningxia, Gansu, and Yunnan have strengthened their economic ties with other provinces, gradually integrating into the economic network. This is associated with China's implementation of policies such as the Belt and Road Initiative and the rural revitalization strategy. In 2023, the overall network structure became more balanced, with closer economic connections between provinces and the basic formation of coordinated regional economic development, creating a favorable situation where each province is intertwined with others.

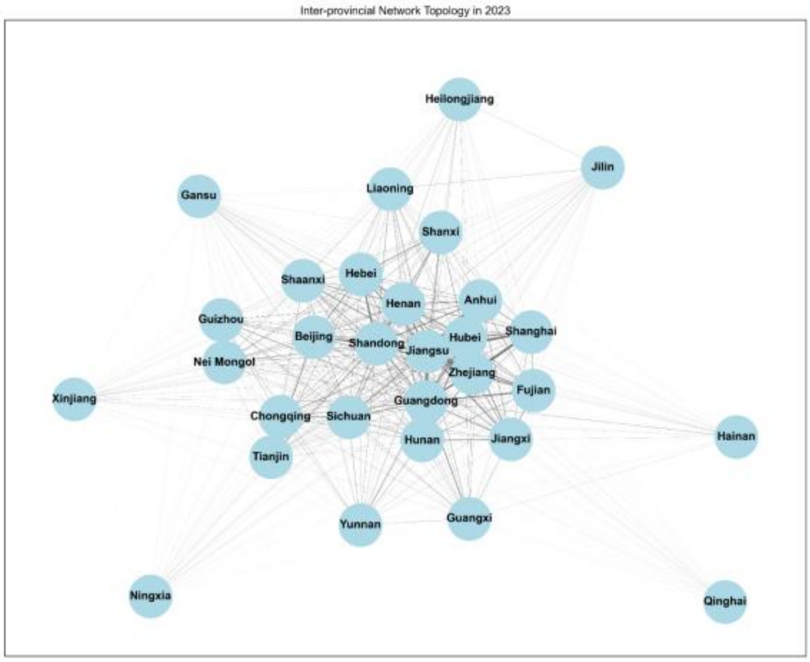

Figure 6. Interprovincial network topology in 2023

3.3. Comparison with other data

3.3.1. Comparison with GDP

The table below compares the Public Relations (PR) values with GDP figures of China's top five provinces in 2014, 2019, and 2023. The "nan" indicator represents provinces that did not rank among the top five in their respective years, with PR values serving as a key measure of calculation validity.

PR values reflect a province's pivotal role in China's economic network. Jiangsu Province has maintained its top-five PR ranking for three consecutive years, solidifying its position as a economic hub. Since 2014, Zhejiang Province has leveraged e-commerce logistics and digital platforms to strengthen industrial collaboration across provinces, achieving a strategic leap from an "economic powerhouse" to a "cyber powerhouse". GDP metrics demonstrate Guangdong's dominance: Jiangsu and Shandong have consistently ranked among the top five for three years with rising values. Guangdong leads with its dual-engine strategy of "foreign trade + technological innovation", Jiangsu follows closely with "manufacturing clusters + county-level economic vitality", while Shandong secures third place through its "heavy industry + agriculture" foundation. Post-2019, the Chengdu-Chongqing Economic Circle strategy boosted industrial synergy between electronics manufacturing in Chengdu and manufacturing in Chongqing. Meanwhile, Sichuan's elevation from a "western regional center" to a "economic node" via the New Western Land-Sea Corridor initiative drove explosive GDP growth.

The high overlap between PR values and GDP rankings among the top five provinces demonstrates that economic strength forms the foundation of network influence. This metric effectively identifies core economic zones through lagging, compensatory, and fluctuating patterns that perfectly align with provincial development stages. Essentially, PR values don't replicate GDP rankings but dynamically and accurately map provinces' true economic influence from a network connectivity perspective. This approach not only reflects economic fundamentals but also sensitively captures both short-term fluctuations and long-term transformations in economic network interactions, serving as an effective tool to measure the collaborative development level of provincial economic networks.

Table 4. PR Values and GDP of Top 5 Provinces (2014, 2019, 2023)

Province	PR Value			GDP		
	2014	2019	2023	2014	2019	2023
Anhui	0.054848	nan	0.053488	nan	nan	nan
Sichuan	nan	nan	nan	nan	nan	60132.9
Shandong	0.083050	0.069410	0.072041	50774.8	70540.5	92068.7
Guangdong	0.057318	0.069095	0.067848	68173	107987	135673
Jiangsu	0.111127	0.111104	0.112271	64830.5	98656.8	128222
Henan	0.060881	0.054609	nan	34574.8	53717.8	nan
Zhejiang	nan	0.071315	0.073839	40023.5	62462	82553.2

3.3.2. Comparison with PCA method

Analysis of PageRank value trends across provinces from 2012 to 2023 reveals distinct regional patterns: Jiangsu maintained consistently high PR values, reaching 0.1123 in 2023, while Zhejiang demonstrated rapid growth from 0.0526 to 0.0738. The synergy between digital economy and industrial development has amplified network influence. Guangdong's PR fluctuated between 0.0651 and 0.0718, slightly declining to 0.0678 in 2023 – a potential reflection of enhanced internal circulation within the Guangdong-Hong Kong-Macao Greater Bay Area. Sichuan's PR value notably rose to 0.0735 post-2018, driven by the Chengdu-Chongqing Economic Circle strategy.

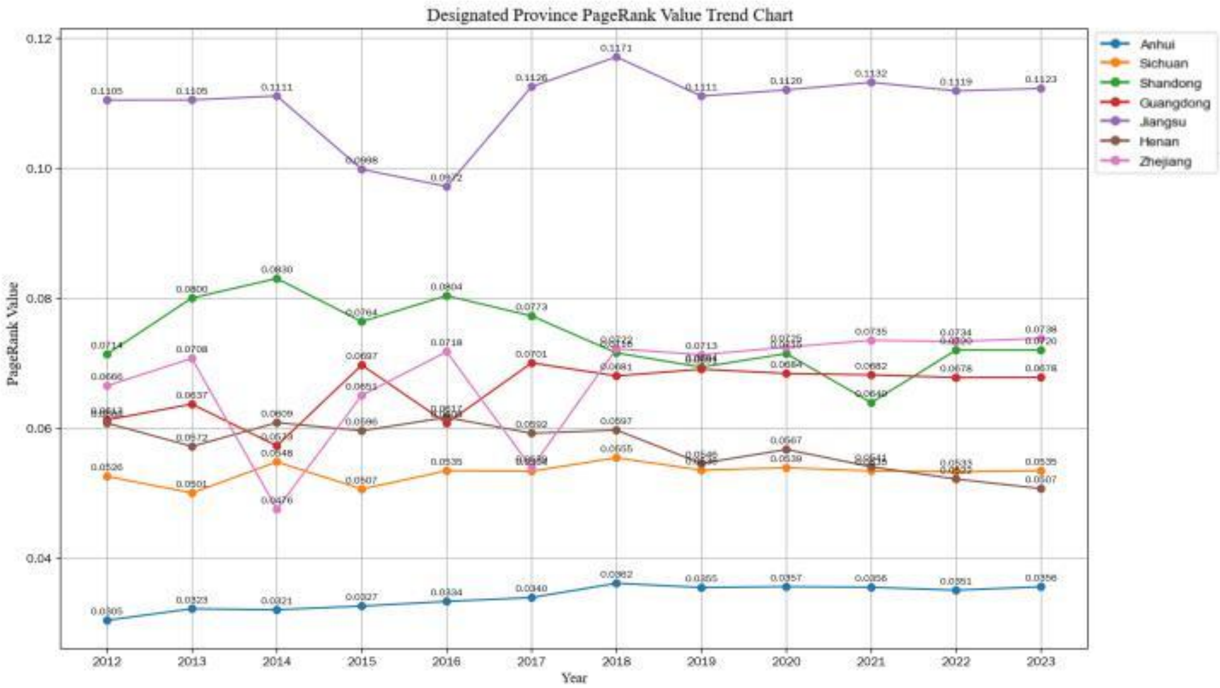

Figure 7. PageRank value change trend in major provinces

The PCA trend chart shows Zhejiang's composite network value skyrocketing from 9.49 to 21.65, a 128% surge driven by digital economy and private sector growth. Sichuan outpaced traditional powerhouses with 20.99 in 2023, while Jiangsu maintained its strong performance at 15.25 – though slightly lower than 2012 levels. Despite retaining manufacturing advantages, Jiangsu's growth has slowed. Guangdong held steady at 19.99, buoyed by foreign trade and technological innovation.

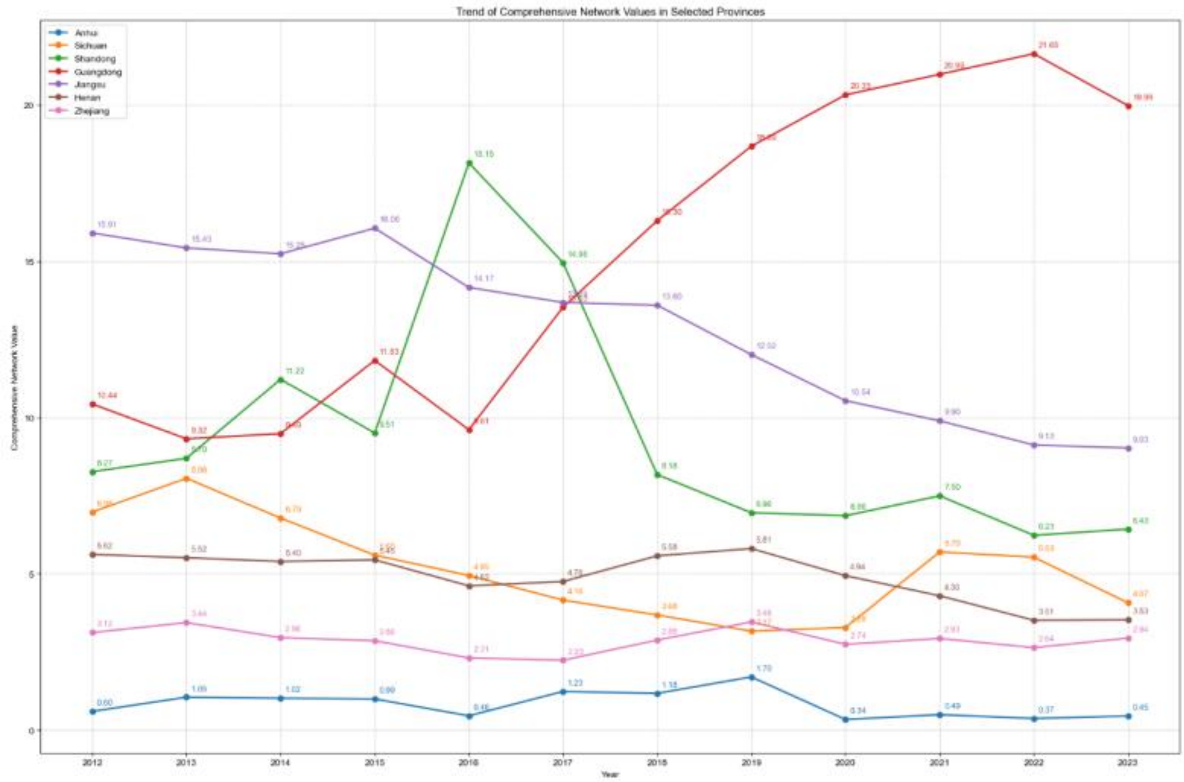

Figure 8. Changes in comprehensive network in major provinces

Both datasets demonstrate the stability of eastern core provinces. However, Zhejiang has achieved a "leapfrogging" through innovation, while Sichuan and Anhui in central-western regions have risen via policy dividends. Henan's position declined due to lagging industrial transformation. The key difference lies in their evaluation metrics: PR value emphasizes the importance of economic network nodes, whereas PCA's comprehensive network value integrates multiple factors, more prominently highlighting the comprehensive strength enhancement of Zhejiang and Sichuan.

4. Conclusion

The investment data primarily originates from the Qingke PEDATA institutional database, where incomplete coverage of small and medium-sized investment events may introduce biases in the investment network. The population network analysis focuses solely on permanent residents and natural population growth rates while excluding migrant population data, which fails to comprehensively reflect population mobility dynamics. Future research could expand data sources by integrating investment data from other industries and sectors, incorporating migrant population statistics and transportation data to analyze economic linkages shaped by population mobility. By examining policy implementation timelines and technological innovation events, we can assess how external factors influence network structure and node significance. Finally, spatial econometric methods combined with complex network visualization techniques will enable more direct and in-depth exploration of interprovincial economic linkages' spatial spillover effects and their intricate evolutionary patterns [24-25].

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