agriculture

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Spatial Analysis of Intercity Migration Patterns of China's Rural Population: Based on the Network Perspective

Yihu Zhou [1,*], Huiguang Chen [1] and Tingting Fang [2]

1 College of Public Administration, Nanjing Agricultural University, Nanjing 210095, China; chenhuiguang@njau.edu.cn
2 Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China; ttfang@niglas.ac.cn
* Correspondence: 2016209024@njau.edu.cn

Abstract: Since entering the 21st century, many developing countries around the world have begun to enter a stage of rapid urbanization; large-scale "rural-urban" population migration has become a typical social phenomenon in these countries. Against this backdrop, this paper aims to elucidate the spatial migration characteristics of rural populations and to discuss future rural–urban development strategies. For this purpose, this paper takes China as a case and employs methods such as spatial autocorrelation analysis, hotspot analysis, and network analysis to construct an intercity migration network of rural migrants and analyze its spatial characteristics and internal structure. The results indicate that the migration pattern of the rural population exhibits notable spatial clustering features. Cities in the eastern and central regions are, respectively, hotspots for the inflow and outflow of rural populations, with internal migration dominating in western cities and relatively inactive rural population movements in northeastern cities. Municipalities directly under the central government, sub-provincial cities, and provincial capitals show a significant tendency to attract rural populations, while prefecture-level and county-level cities mainly radiate rural populations outward. Cities nationwide form seven major clusters in the migration network, and these clusters exhibit distinct structural characteristics. Rural population migration is influenced by various factors. In the future, considerations should focus on the county as the primary unit, attracting rural populations for local employment, and promoting rural revitalization and agriculture development. The findings of this paper are of reference significance not only to China but also to many developing countries with similar national conditions in the world.

Keywords: labor force; core cities; migration network; city cluster; hotspot analysis; network analysis

Citation: Zhou, Y.; Chen, H.; Fang, T. Spatial Analysis of Intercity Migration Patterns of China's Rural Population: Based on the Network Perspective. *Agriculture* **2024**, *14*, 655. https://doi.org/10.3390/agriculture14050655

Academic Editor: Sanzidur Rahman

Received: 10 March 2024
Revised: 15 April 2024
Accepted: 22 April 2024
Published: 24 April 2024

1. Introduction

A labor force is one of the key factors influencing productivity development; hence, research on population migration has been an important and widely discussed topic globally. After entering the 21st century, a new wave of urbanization began to rise around the world. According to forecasts by the United Nations Population Division, by the year 2050, 70% of the global population will reside in urban areas, with rural–urban migration being the primary driver of urban population growth [1,2], particularly in developing countries in Asia and Africa [3]. Due to the lack of initial accumulation, these countries often opt for an unbalanced development strategy, concentrating limited resources in certain advantageous regions [4]. On the one hand, this provides an effective approach for national economic development, playing a significant role in economic stimulation. On the other hand, the resulting rapid urbanization and industrialization processes widen the economic gap between regions, leading to substantial population movements between rural and urban areas. For instance, according to World Bank data in 2022, compared to 2010, the urbanization rates of countries such as Vietnam, India, and Indonesia have increased by 8.38%, 4.97%, and 7.99%, respectively. The urban populations have increased by 11.3059 million, 126.6048 million, and 38.8999 million, respectively. The substantial rural–urban migration has not only promoted the overall economic development but also brought forth a range of new issues for these countries. Examples include the imbalance of regional development [5], the discrimination and lack of protection for rural migrants [6], and the problem of "urban diseases" including congestion and pollution in big cities [7].

China is also one of these countries. Since the reform and opening up in 1979, China has also adopted an unbalanced development strategy. With the rapid development of the economy, an increasing number of rural residents have chosen to migrate to urban areas in pursuit of more job opportunities and higher economic incomes, and rural–urban migrant work became a crucial means for farmers to increase their income [8]. Over several decades of development, the rural migrant population has emerged as a vital factor propelling socio-economic advancement. According to the National Bureau of Statistics of China, nearly 300 million rural people are migrating every year; their prolonged and substantial presence represents a distinctive feature in the current population migration pattern in China. Rural migrants are vital labor resources crucial for the development of both urban and rural areas. Consequently, the Chinese government places a high priority on and supports the orderly migration and rational distribution of rural migrant populations, considering them crucial measures to safeguard the social and economic development. The government has proposed the strategies of "new urbanization" and "rural revitalization", trying to guide the reasonable migration of rural populations through the city distribution structure, so that urban and rural areas can achieve coordinated development.

At the same time, rural–urban migration has also garnered increasing attention from scholars worldwide. Using the data of different countries or regions, they systematically analyzed the causes of rural migration, the impact of population migration on urban and rural areas, the welfare guarantees for rural migrants, and the social integration of rural migrants. However, due to limitations in data availability, the spatial analysis of rural population migration characteristics has always been challenging. Such studies not only require a large sample size as support but also demand that all samples must be of the rural population, which general databases often fail to meet [9]. Although in recent years, scholars have also utilized cell phone signaling data to analyze the spatial migration patterns of floating populations [10,11], such data cannot distinguish whether migrants originate from urban or rural areas [9]. In fact, rural migrants are just a subset of floating populations, and rural migrants in developing countries cannot fully enjoy urban residents' welfare benefits and may encounter discrimination and exclusion [12]. Migration is often viewed as a means to increase economic income rather than a lifelong goal for rural migrants. This leads to differences between rural migrants and urban migrants in terms of resource endowment, migration purposes, employment scope, welfare guarantees, etc. These differences necessitate separate research for both groups rather than lumping them together. The China Migrants Dynamic Survey (CMDS) organized by the National Health Commission provides assistance in addressing this issue. This survey not only covers the whole of China, but also records the detailed migration information and identity attributes (rural population or not) of each respondent, creating possibilities for spatial analysis of rural population migration characteristics.

In the above context, China, as a typical country with a large number of rural migrants, can serve as a valuable subject for research on rural migration. Analyzing the spatial migration patterns of rural migrants across different cities in China can provide insights into the migration laws of rural populations. Therefore, this paper, relying on CMDS data, employs network analysis tools to construct an intercity migration network for rural migrants and analyzes its key features such as critical cities, pathways, and network structure to reveal the spatial flow patterns of rural migrants in terms of size and direction. The objective is to elucidate the spatial migration characteristics of rural populations, reveal the relationships between regions in population migration, discuss future rural–urban development strategies, and address some unanswered questions in existing studies. Specifically, what are the migration characteristics of rural populations, and are they the same as those of the overall floating population? What roles do different cities play in the migration of rural populations? Within the same country, do rural population migration activities exhibit regional differences and manifest different migration characteristics in different areas? These efforts can not only serve as references for formulating relevant rural development policies and population migration policies in China but also provide insights for other countries at a similar developmental stage, helping them avoid social or economic issues arising from population migration during subsequent stages of development.

In terms of the paper structure, this paper consists of six sections. Section 1 presents the research background and objectives. Section 2 is the review of the relevant literature and the research hypotheses based on it. Section 3 describes the data and methods employed in this study. Section 4 provides specific analysis results of the rural population migration network. Section 5 primarily discusses the causes for the formation of a rural population migration network and the enlightenment gained from this study. Finally, Section 6 presents the conclusions of this paper.

2. Literature Review and Research Hypotheses

The issue of rural–urban migration has attracted considerable attention and research from scholars internationally. The existing studies have varied focuses and perspectives. In terms of the impact of rural population migration on urban and rural development, P. Rai [13] analyzed population migration in rural areas of western India and its resulting social changes. He found that seasonal labor migration affects landholding farmers, landless laborers, and production relations in villages. Migrants form a new class and attempt to alter existing social norms and statuses, leading to increased social tension in rural areas. C. Simon [14] examined the impact of rural–urban migration on the rural economic environment, discovering that unrestricted rural migration reduces the average income of rural residents in developing countries, with the loss of rural skilled workers exacerbating this phenomenon. J. Oliveira [15] and other scholars analyzed the impact of rural population migration in Brazil. They found that rising temperatures led to a decline in agricultural yields, prompting a significant migration of rural populations to more developed areas. Moreover, they predict a continued increase in migration rates in the future, contributing to a demographic dividend for developed regions and further widening the economic gap between developed and underdeveloped areas. The insights from these studies are that as an important labor resource, the migration activities of a rural population is crucial for regional development and needs to be scientifically guided rather than arbitrarily implemented. This also highlights the importance of analyzing the topic of rural population migration.

Analyzing the reasons for rural population migration is also a focal point of scholarly inquiry, and economic factors are generally considered the primary drivers of population migration. Scholars such as A. Nandy [16] investigated the impact of the Rural Employment Guarantee Scheme in India on rural out-migration. The objective of this scheme is to curb rural out-migration by guaranteeing demand-driven employment opportunities in rural areas. However, rural residents, upon realizing the higher income potential provided by non-agricultural jobs, often become more inclined to migrate out of rural areas in search of more job opportunities. C. Villalobos [17] studied the relationship between rural–urban migration in Chile and territorial income disparities. It was found that the income gap observed by potential migrants encouraged rural migration, and household constraints of potential migrants, such as welfare for family members, might serve as pull or push factors. A. Akay [18] analyzed the relative concerns of rural migrants in China and discovered that the income level of rural hometowns and the income prospect of urban areas are the primary concerns for rural migrants. D. Phan [19] studied rural–urban migration and inequality in Vietnam, revealing that economically developed provinces are the primary destinations for rural migrants. While interprovincial work has effectively reduced population poverty, discrimination against migrants remains a significant issue. D. L. Nguyen [20], N. Mohabir [21], and other scholars have also reached similar conclusions. The insights gleaned from these studies for this paper are that the development gap between urban and rural areas serves as the main reason for rural populations to leave rural areas, and the pursuit of higher economic income is the main purpose of rural population migration. Consequently, regions offering greater employment opportunities are poised to become the primary destinations for rural population migration.

In the analysis of spatial migration characteristics, restricted by data availability, most studies treated "all migrants" as a collective subject without distinguishing between rural and urban migrants. For example, D. M. Michele [22] studied the migration pathways and spatial distribution of internal migrants in Libya, finding that migrants were more likely to move to areas with higher economic opportunities, lower conflict intensity, and better accessibility. Shen [23], utilizing the 2015 China Migrants Dynamic Survey data and network analysis, studied the spatial structural characteristics of inter-provincial population flows, noting that the overall density of inter-provincial population flow networks was low. The majority of inter-provincial population flows were unidirectional, with net outflows from economically relatively underdeveloped regions and net inflows into economically prosperous areas. Wang [24], based on census data, employed spatial error models to separately analyze inter-provincial and intra-provincial migration patterns, highlighting that increased job opportunities and higher wages were primary motivators. Inter-provincial migrants tended to cluster spatially, preferring entry into large cities, while intra-provincial migrants exhibited a more dispersed distribution. The insights these studies bring to this paper are that rural population migration occurs spatially as a process from underdeveloped regions to developed regions. Economically disadvantaged areas tend to be hotspots for rural population outflows, whereas economically developed regions serve as hotspots for rural population inflows.

Meanwhile, although data limitations make it difficult for scholars to analyze the spatial characteristics of rural population migration at a macro level, there are still some scholars attempting to analyze this issue at a smaller spatial scale. Scholars such as Zou [25] have conducted studies on the spatial mobility of rural populations based on local research data, focusing on individual provinces. They found that the main spatial scales of rural population migration are within counties and between provinces. On the contrary, scholars like Long [26] have reached different conclusions. Through comprehensive analysis of multiple sets of sample data, they found that the migration range of rural populations is primarily within townships, with the proportion moving to other provinces being the lowest. Scholars like Mei [27] and others have utilized spatial econometric methods to analyze the regional clustering of rural migrant populations. They found that coastal developed cities attract the largest number of rural migrant populations, with their aggregation areas closely aligned with industrial layouts. Significant differences were observed on either side of the "Hu Huanyong Line". Similar results were obtained by scholars such as Xue [28]. It can be seen that these studies, conducted within a smaller spatial scale, have inconsistent conclusions. This also brings about some new insights for this paper, including that, even within the same country, rural population migration activities in different regions may exhibit different characteristics. This may be attributed to the diverse economic, cultural, and geographic environments in each region, leading to distinct migration characteristics of rural populations in different areas.

In summary, all the studies above hold significant importance for the analysis of the migration characteristics of rural populations. However, due to the substantial numbers of the rural migrants, each migrant forms a spatial connection from the place of origin to the destination, resulting in an overall pronounced networked characteristic. However, constrained by data limitations, existing studies often have to resort to traditional spatial analysis methods, only being capable of analyzing the spatial distribution characteristics of migrants, unable to further investigate detailed migration paths, regional relationships, city clusters, and other internal structural features of migration. Moreover, existing studies have focused more on the role of large cities in population migration, neglecting the roles and positions of small cities. However, in developing countries, small cities constitute the majority and deserve more attention in research. Considering this, based on the CMDS data covering the whole Chinese mainland, this paper includes all cities on the Chinese mainland into the analysis and uses network analysis methods to further analyze the issue of rural population migration. Meanwhile, in light of insights gleaned from the extant literature, we propose the following hypotheses pertaining to the research questions in this paper:

Hypothesis 1: *In the migration network, cities in the economically advantaged eastern regions of China will emerge as core nodes attracting rural populations.*

Hypothesis 2: *In the migration network, rural population migration activities in different regions exhibit distinct characteristics, resulting in varying internal structures among different city clusters.*

Hypothesis 3: *Some relatively economically underdeveloped small cities will also emerge as core nodes in the migration network, but their role within the network may differ from that of larger cities.*

Through the analysis and validation of the aforementioned hypotheses, this study aims to make new contributions to the migration literature. Specifically, by treating rural migrants as a distinct research subject, this paper contrasts with previous studies that did not differentiate between urban and rural migrants, thereby elucidating the unique characteristics of rural population migration. Furthermore, this paper encompasses nearly all cities within a single country, examining the roles and positions of individual cities in rural population migration activities, inter-city migration relationships, and disparities in migration characteristics across different regions. These aspects represent previously unexplored dimensions in migration studies.

3. Materials and Methods

3.1. Data Source

The data utilized in this study were derived from the 2017 China Migrants Dynamic Survey (CMDS 2017) conducted by the National Health Commission of China. The survey employed a stratified, multi-stage, probability-proportional-to-size (PPS) sampling method. Approximately 8500 survey points were selected across 31 provinces in mainland China. The survey achieved comprehensive coverage of all county-level and above cities nationwide. Information was collected from non-local migrants (cross-county migrants) aged 15 and above who had resided in their destinations for at least one month, excluding non-labor-force groups such as students. A total of 169,990 valid samples were obtained. Through a selective process based on household registration status, this study focused on a subset of rural migrants, comprising 132,555 samples, which constituted 77.98% of the total dataset. The strength of this dataset lies in its national coverage, substantial sample size, and accurate acquisition of both the destination and household registration information for each sample during the survey. This precision enables the visualization of migration paths, offering the feasibility to construct a precise intercity migration network for the rural populations and analyze their patterns of migration.

During the data preprocessing process, non-data regions such as Hong Kong and Macau, as well as non-spatial-entity units such as the Heilongjiang Provincial Bureau of Agriculture and Reclamation and the Forestry Bureau, were excluded. The data were then geographically mapped by city basis. Ultimately, out of the total of 375 cities nationwide, data on rural population migration were present in 363 cities, accounting for 96.80% of the total number of cities. The dataset encompassed 130,518 samples of rural migrants, representing 98.46% of the total rural population samples. This focused approach, filtering out regions with no data and non-spatial entities, ensured a comprehensive and spatially accurate representation of rural population migration across the country, facilitating robust analysis of migration patterns at the city level.

Table 1 presents the basic statistical characteristics of the samples used in this study. It can be observed that individuals aged 26 to 55 constitute the primary demographic of rural migrants in China, accounting for over 80% of the total sample. This aligns with the general pattern of labor migration, where individuals in their prime working ages are more inclined to seek greater job opportunities and higher economic incomes through migration. In terms of educational attainment, similar to many other developing countries [6], rural migrants in China generally have low levels of education. Those with a middle school education represent half of the total sample, while less than 10% have received a college education. Regarding marital status and gender, over 80% of migrants are married, and there are more male migrants than female migrants. This also reflects a common phenomenon in labor migration in many developing countries [7], where males predominantly seek employment opportunities outside their hometowns to augment family income, while females often remain at home to care for elderly family members and children. In terms of migration characteristics, the average duration of migration for rural migrants in China is 12.09 years, with over half of them having more than 10 years of work experience outside their hometowns. Rural migrants in China have an average migration experience covering 2.16 cities, but nearly half of them have migrated to only one city. The duration of migration may be associated with age, as older individuals may have longer migration time, but the statistical results do not entirely support this viewpoint. Among individuals under 55 years old, migration time tends to increase with age; however, among those over 55 years old, migration time actually decreases. Additionally, concerning the relationship between the number of cities migrated to and migration time, individuals under 45 years old have shorter migration times compared to those over 45 years old, yet they have visited more cities. Evidently, younger individuals may be more inclined to explore working opportunities in different cities.

Table 1. Basic statistical characteristics of the samples.

Characteristic	Ratio	Characteristic	Ratio
Age (year)	Average = 37.90	Marriage	85.65%
15–25	12.09%	Gender	
26–35	33.48%	Male	57.35%
36–45	29.24%	Female	42.65%
46–55	20.09%	Migration time (year)	Average = 12.09
56–65	3.93%	<3	11.20%
>65	1.18%	3–5	13.37%
Educational attainment	Average = 3.15	6–10	23.58%
Have not attended school = 1	3.45%	>10	51.85%
Elementary school education = 2	18.71%	Number of cities migrated to	Average = 2.16
Middle school education = 3	49.19%	1	48.23%
High school education = 4	19.18%	2	27.08%
Junior college education = 5	6.63%	3	11.94%
College education = 6	2.70%	>3	12.75%
Post-graduate education = 7	0.14%		

3.2. Research Methods

3.2.1. Spatial Autocorrelation Analysis

Spatial autocorrelation refers to the potential interdependence among elements within the same distribution area, and Moran's *I* is a metric used to measure this phenomenon [29,30]. In this study, we employed this method to investigate the spatial autocorrelation of rural population migration across different cities and to elucidate the clustering characteristics of such migration in a spatial context.

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where z_i is the deviation of an attribute for feature i from its mean, $w_{i,j}$ denotes the spatial weight between feature i and j, and S_0 is the aggregation of all spatial weights.

3.2.2. Hotspot Analysis

Hotspot analysis involves calculating the relationships between a certain feature and its neighboring features within a distribution area, thereby identifying spatial hotspots and cold spots that have statistical significance. The statistical measure used for this purpose is represented by the *Getis-Ord Gi** statistic [31,32]. This method has been employed by scholars across various fields to analyze issues related to spatial clustering. Analyzing the spatial distribution of populations is also among the application domains of this method, and it has shown promising effects in existing research [33,34]. In this study, we applied this method to identify key areas in the inflow and outflow of rural populations.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \overline{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (2)$$

where x_j represents the attribute value of feature j, and $w_{i,j}$ represents the spatial weight between features i and j.

3.2.3. Network Analysis

In 1736, Swiss mathematician L. Euler provided a solution to the famous "Seven Bridges of Königsberg" problem, thereby initiating a new branch of mathematics known as graph theory and geometric topology. This groundbreaking work laid the foundation for understanding networks. In the mid-20th century, with the invention of computers, scholars began to explore the use of mathematical matrices to describe graphs. In 1959, Hungarian mathematicians P. Erdős and A. Rényi combined statistics with graph theory, proposing the "Random graph model", laying the foundation for analyzing networks and their statistical properties [35,36]. Building upon this foundation, two seminal articles can be regarded as the hallmark of contemporary network science. One is the paper titled "Collective Dynamics of 'Small-World' Networks" published by American scholars D. Watts and S. Strogatz in 1998 [37]. The other is the paper titled "Emergence of Scaling in Random Networks" published by A. Barabási and R. Albert in 1999 [38]. These two papers respectively revealed the small-world characteristics and scale-free properties of networks and established corresponding models to elucidate the mechanisms behind these features. From then on, network theory began to receive increasing attention from scholars, with contributions from M. Newman, J. Blumenstock, S. Aral, M. Macy, V. Blondel, and others in the field. Network analysis methods also started to find increasingly widespread applications across various domains.

Networks are characterized by a large number of nodes, diverse connections, network structures, and significant clustering effects [37,39]. The analysis of networks has primarily focused on identifying key nodes and exploring network communities [40]. In recent years, the application of network analysis has expanded to various fields such as international relations [41], transportation networks [42], and population flow networks [43,44], achieving good effects. Rural migrant population reflects the flow of populations between different cities, making it suitable for network analysis. In this network, cities with rural population flows represent the nodes (denoted as i or j), the rural population flow from city i to city j represents the edges (denoted as a_{ij}), and the edge weights (denoted as w_{ij}) will be determined by the scale of the population migrating between city i and city j, reflecting the strength of population migration relationships between cities. Finally, the rural population flow relationships between n cities constitute a directed network. The measurement indicators for this network include the following aspects:

(1) Node Degree

Node degree can be divided into in-degree (K_i^{in}) and out-degree (K_i^{out}). A city's in-degree reflects the number of cities from which rural migrants flow into that city. The higher the in-degree, the more cities contribute to the rural population inflow to that specific city. On the other hand, the out-degree of a city reflects the number of cities to which the rural population from that city migrates. A higher out-degree indicates that the rural population from that city flows into more external cities.

$$K_i^{in} = \sum_{j=1}^{n} a_{ji} \tag{3}$$

$$K_i^{out} = \sum_{j=1}^{n} a_{ij} \tag{4}$$

(2) Node Strength

Node strength can be divided into in-strength (S_i^{in}) and out-strength (S_i^{out}). The in-strength of a city reflects the scale of the rural population that moved into that city, with a higher in-strength indicating a larger influx of rural population. Conversely, the out-strength of a city reflects the scale of the rural population that moved out of that city, with a higher out-strength indicating a larger outflow of rural population from that city.

$$S_i^{in} = \sum_{j=1}^{n} a_{ji} w_{ji} \tag{5}$$

$$S_i^{out} = \sum_{j=1}^{n} a_{ij} w_{ij} \tag{6}$$

(3) Node Importance

Node importance (I_i) is a metric that measures the importance of each city in the network. The higher the value, the more active the rural population migration is for that city. In the equation, S_i represents the summation of the rural population migrating in and out of the i city.

$$I_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \times 100 \tag{7}$$

(4) Node Symmetry

Node symmetry (R_i) reflects the population throughput tendency of each city in the network. A higher value indicates a more pronounced tendency of the city to attract rural populations, while a lower value suggests a tendency for the city to emit rural populations outward.

$$R_i = \frac{S_i^{in} - S_i^{out}}{S_i^{in} + S_i^{out}} \times \left| S_i^{in} - S_i^{out} \right| \tag{8}$$

(5) Community Detection

Community in a network refers to a closely connected group of nodes, also known as a cluster, and community detection is the process of making explicit the various groups implicit in the network, serving as an essential approach to understanding and analyzing network structures. When there is a close rural population migration relationship between some cities, they will form a city cluster. There are a large number of rural population migration activities between cities within the cluster, while interactions between cities from different clusters are relatively limited. This approach allows for an analysis of whether rural population migration exhibits regional characteristics. In this study, the Louvain community detection algorithm is employed to identify internal city clusters in the Chinese rural population migration network [45]. This algorithm iteratively calculates the modularity ΔQ, leading nodes in the network to gradually converge and ultimately form a stable cluster structure. The calculation formula for ΔQ is as follows:

$$\Delta Q = \left[\frac{\sum G^{in} + 2k_i^{in}}{2M} - \left(\frac{\sum G^{tot} + k_i}{2M} \right)^2 \right] - \left[\frac{\sum G^{in}}{2M} - \left(\frac{\sum G^{tot}}{2M} \right)^2 - \left(\frac{k_i}{2M} \right)^2 \right] \quad (9)$$

where $\sum G^{in}$ represents the sum of weights of all edges in community G; $\sum G^{tot}$ is the sum of weights possessed by nodes under community G; k_i^{in} is the sum of weights from node i to nodes in community G; k_i is the node strength of node i; M is the sum of weights of all edges in the entire network.

4. Results

4.1. Analysis of Spatial Characteristics of Rural Population Migration

4.1.1. Spatial Autocorrelation of Rural Population Migration

Using the ArcGIS 10.0 platform, a comprehensive analysis of the nationwide global spatial autocorrelation for the 363 cities was conducted. During the calculation, the "Inverse Distance" and "Euclidean Distance" methods were employed to conceptualize the spatial relationships between features. The results revealed that the Moran's I indices for both inflow and outflow directions were 0.1055 and 0.2119, with corresponding Z-values of 7.88 and 16.61, respectively. The p-values for both directions were less than 0.001. This indicates a significant spatial autocorrelation of rural population migration at the national scale. The intercity relationships in rural population migration exhibited pronounced spatial clustering characteristics and spatial dependence effects. In other words, there is a commonality in rural population migration between neighboring cities, where a city with a higher inflow (or outflow) of rural migrants tends to be surrounded by cities of a similar type. This spatial tendency manifests as a regional clustering pattern in geographical space. Furthermore, the Moran's I index for population outflow is higher than that for population inflow, suggesting a more pronounced spatial dependence effect in rural population outflow. This indicates a greater likelihood of extensive regions with significant rural population outflow in geographical space.

4.1.2. Spatial Distribution of Hot and Cold Spots in Rural Population Migration

Utilizing the same spatial conceptualization methods based on the ArcGIS platform, the Getis-Ord Gi* values for various cities were computed. As depicted in Figure 1a, it is evident that the eastern coastal cities remain focal points attracting the rural population in China. The primary regions include the surrounding areas of the Bohai Bay, the Jiaodong Peninsula, Jiangsu Province, Shanghai, Zhejiang Province, Fujian Province, and Guangdong Province. Correspondingly, the central regions, encompassing Shanxi Province, Henan Province, Anhui Province, Hubei Province, and Hunan Province, along with the western border areas, exhibit pronounced spatial cold spots characterized by a lower inflow of rural population. Overall, the inflow pattern of China's rural population reveals a spatial distribution of "west cold, east hot".

Furthermore, as indicated in Figure 1b, the central regions emerge as hotspots for the outflow of China's rural population, primarily dominated by Henan Province, Anhui Province, Hubei Province, and Sichuan Province. Elevated levels of emigration are also observed in the southern part of Shanxi Province, southwestern Shandong Province, northern Jiangsu Province, and northern Guizhou Province. Cold spots for rural population outflow are predominantly situated in the peripheral regions of the Chinese mainland, including the surrounding areas of the Liaodong Peninsula, northwestern Xinjiang Autonomous Region, northwestern Yunnan Province, the periphery of the Leizhou Peninsula, and Hainan Province. In summary, the outward migration pattern of China's rural population exhibits a spatial arrangement characterized by "external cold, internal hot".

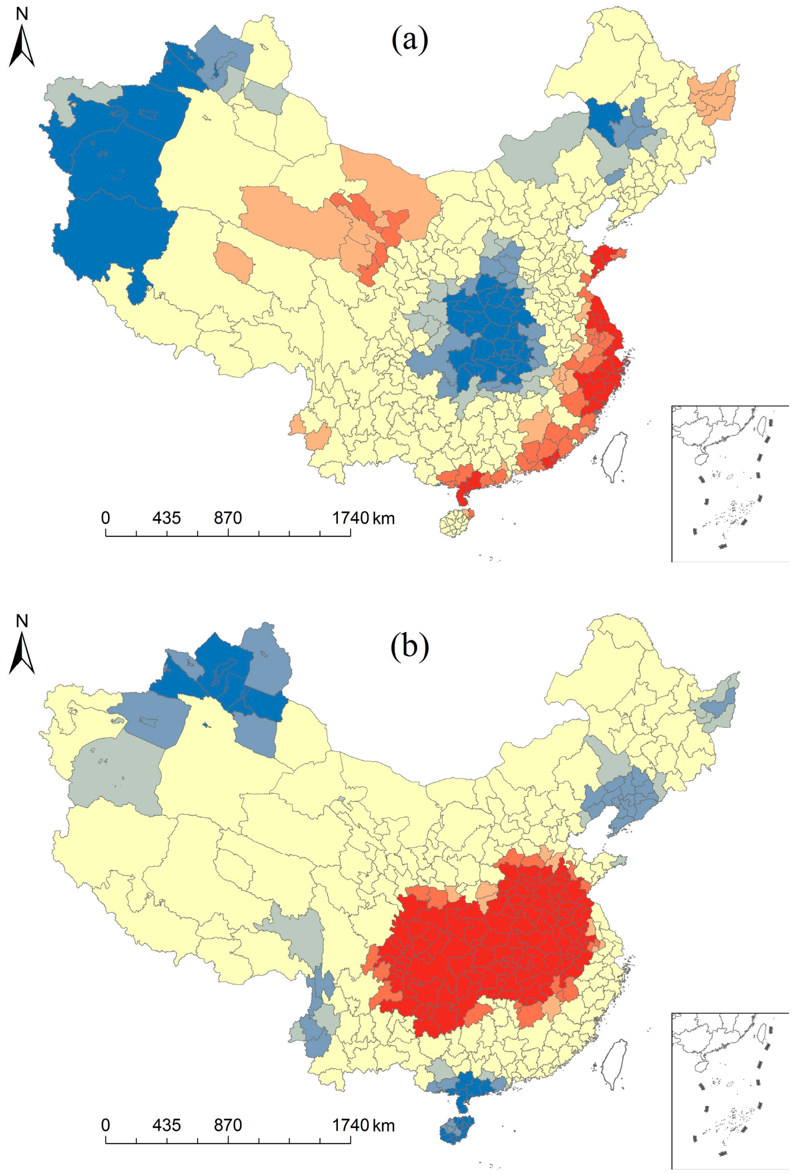

Figure 1. (**a**) Rural population inflow hotspots and cold spots. (**b**) Rural population outflow hotspots and cold spots. Note: Red represents hot spots, and blue represents cold spots.

4.2. Network Characteristics Analysis of Rural Population Migration

Utilizing the Gephi platform, a migration network of rural populations in China was constructed and analyzed. The results indicate that the network comprises a total of 363 cities, with 17,149 migration relationships among total cities. The overall density of the network is calculated at 0.131. In the context of a nationwide network focusing on rural population migration, these findings reveal characteristics such as extensive coverage, robust factor mobility, and a relatively high network density, as illustrated in Figure 2. In the figure, circles represent different cities, with the size of each circle indicating the scale of rural population migration in that city. Lines represent rural population migration flows between different cities, while different colors denote the cities and migration flows belonging to different city clusters. Subsequent sections of the paper will analyze each of these elements individually.

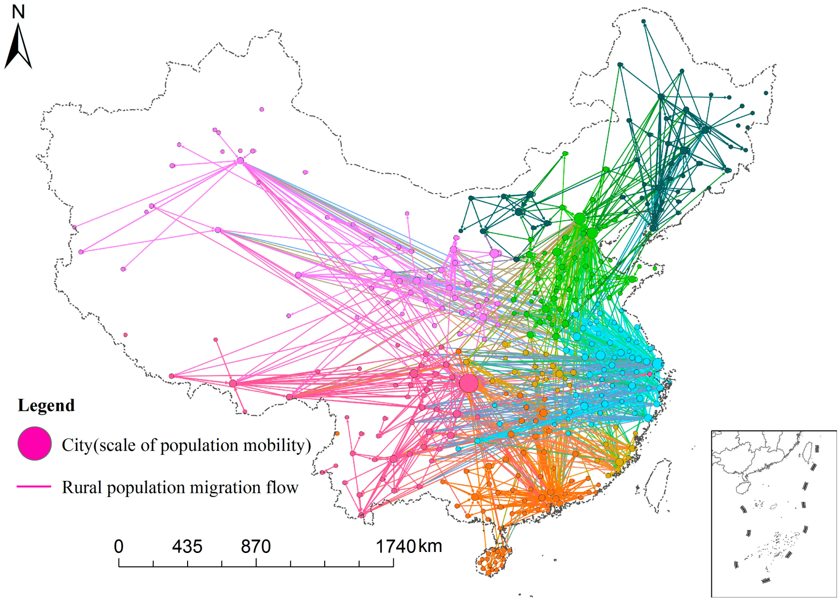

Figure 2. Intercity migration network of rural population.

4.2.1. The Flow Size and Direction of Rural Populations

Table 2 presents the weight matrix for the interregional migration of rural populations across four regions in China. The data represent the ratio of the weights of cities within each region to the total network weight, reflecting the size of rural population movement among cities in different regions. From the table, it is observed that only in the eastern region does the size of inflow migration exceed local migration, with 23.77% of the total rural population in the network migrating from other regions to cities in the eastern region. This highlights the strong absorptive capacity of cities in the eastern region for rural populations. Specifically, the migration ratio from "Central Region cities to Eastern Region cities" reaches 14.50%, making it the primary source of rural populations migrating to the eastern region.

Table 2. Weight matrix of rural population migration in different regions.

Outflow / Inflow	Eastern	Central	Western	Northeast	Total Inflow from Outside
Eastern	15.51%	14.50%	8.04%	1.23%	23.77%
Central	1.21%	16.02%	0.98%	0.08%	2.27%
Western	2.10%	5.08%	28.54%	0.27%	7.46%
Northeast	0.45%	0.45%	0.35%	5.17%	1.24%
Total outflow to outside	3.76%	20.04%	9.37%	1.58%	/

In contrast, the central region is the only region where the outflow migration ratio exceeds the local migration ratio. Approximately 20.04% of the total rural population in the network migrates from cities in the central region to other regions, with the eastern region being its primary destination. Meanwhile, although cities in the western region experience significant rural population movement, a large proportion is attributed to local migration (28.54%), with relatively lower ratios of inflow (7.46%) or outflow migration (9.37%) from outside the region. Cities in the northeastern region exhibit a smaller type of rural population movement, with a tendency toward intra-regional migration (5.17%).

4.2.2. Node Degree and Node Strength of Cities in Different Regions

Figure 3 illustrates the overall characteristics of cities in different regions in terms of in-degree/in-strength and out-degree/out-strength. It can be observed that there are certain differences among cities in different regions regarding their ability to attract or export rural migrants.

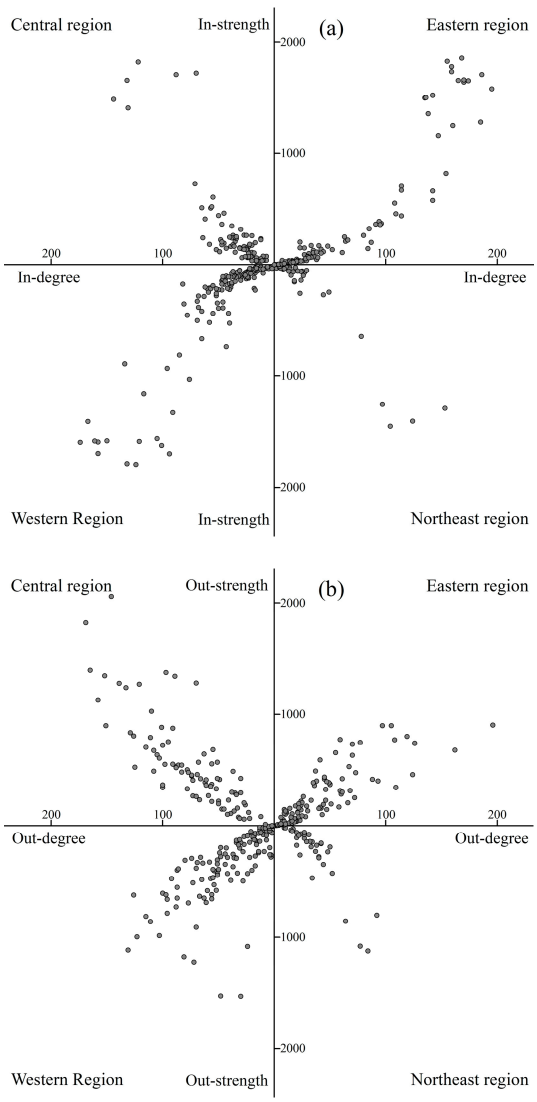

Figure 3. (**a**) Scatter plot of node in-degree/in-strength of cities in different regions. (**b**) Scatter plot of node out-degree/out-strength of cities in different regions.

In terms of node in-degree, Beijing, Tianjin, and Shanghai emerge as cities with the highest in-degrees in the rural population migration network, attracting rural populations from 256, 245, and 238 cities, respectively. Subsequently, cities in the eastern region such as Shenzhen (195) and Hangzhou (186) also exhibit notably high in-degrees in the network. Cities in the western region with notable in-degrees include Chongqing (177), Urumqi (174), Linzhi (167), Xining (161), and Xi'an (158). On the other hand, cities in the central and northeastern regions generally demonstrate lower in-degrees, with only cities like Shenyang (153), Taiyuan (144), Wuhan (132), and Nanchang (131) having relatively substantial in-degrees. Overall, the average in-degree for cities in the eastern region is 65.07, significantly higher than other regions; the western region is at 44.06, while the central and northeastern regions have lower averages at 34.83 and 28.84, respectively.

Regarding node out-degree, Chongqing, Wenzhou, and Zhoukou have the highest out-degrees in the network, with rural populations migrating to 221, 196, and 169 cities, respectively. Notably, cities in the central region exhibit significantly higher out-degrees compared to other regions, with an average out-degree of 74.40. Representative cities include Nanyang (165), Anqing (158), Shaoyang (152), Jingzhou (151), and Fuyang (146). Cities in the eastern, western, and northeastern regions have comparable average out-degrees at 38.73, 37.97, and 33.05, respectively. However, both the eastern and western regions have individual cities with higher out-degrees, such as Chongqing (221), Wenzhou (196), and Taizhou (162). In the northeastern region, the city with the highest out-degree is Harbin, with a relatively modest out-degree of 92.

In terms of node in-strength, cities in the eastern region, specifically Beijing (4509), Shanghai (4465), and Tianjin (4118), emerge as cities with the highest in-strength in the network. The average in-strength for cities in this region reaches 493.04, which is significantly higher than in other regions. In the western region, the average in-strength is 330.89. Except for Chongqing (3550), other cities such as Lhasa (1796), Kunming (1790), and Hohhot (1701) also demonstrate strong capabilities in attracting rural populations. Cities in the central region exhibit an average in-strength of 274.49, with Zhengzhou (1818), Hefei (1719), and Changsha (1705) standing out with higher in-strength values. Conversely, cities in the northeastern region display the weakest attraction capabilities for rural populations, with an average in-strength of only 220.39. Leading cities in this region include Changchun (1451), Dalian (1405), and Shenyang (1289).

Regarding node out-strength, cities in the central region demonstrate significantly higher rural population outflow compared to other regions, with an average out-strength of 540.98. Cities such as Fuyang (2059), Zhoukou (1823), and Nanyang (1398) experience the highest rural population outflow in this region. In the western region, the average out-strength is 348.47, and Chongqing (5065) stands out as the city with the highest out-strength, followed by Ulanqab (1532) and Yulin (1529). Cities in the eastern and northeastern regions exhibit weaker average out-strength values, at 241.88 and 231.95, respectively. Cities with relatively higher rural population outflow in these regions include Suihua (1123), Qiqihar (1080), and Wenzhou (903) (Figure 3).

4.2.3. Differences in Node Characteristics among Cities of Different Levels

Due to differences in resource endowment, cities of different administrative levels exhibit distinct characteristics in the inflow and outflow of rural migrants. As illustrated in Figure 4, the horizontal axis of the figure lists five types of cities, with their administrative levels decreasing from left to right, while the vertical axis reflects their node degree and node strength. Both the average node in-degree and in-strength exhibit similar decreasing trends with the decline of city administrative levels. Conversely, the changes in average node out-degree and out-strength follow a similar pattern, showing an inverted "U-shaped" relationship with city administrative levels.

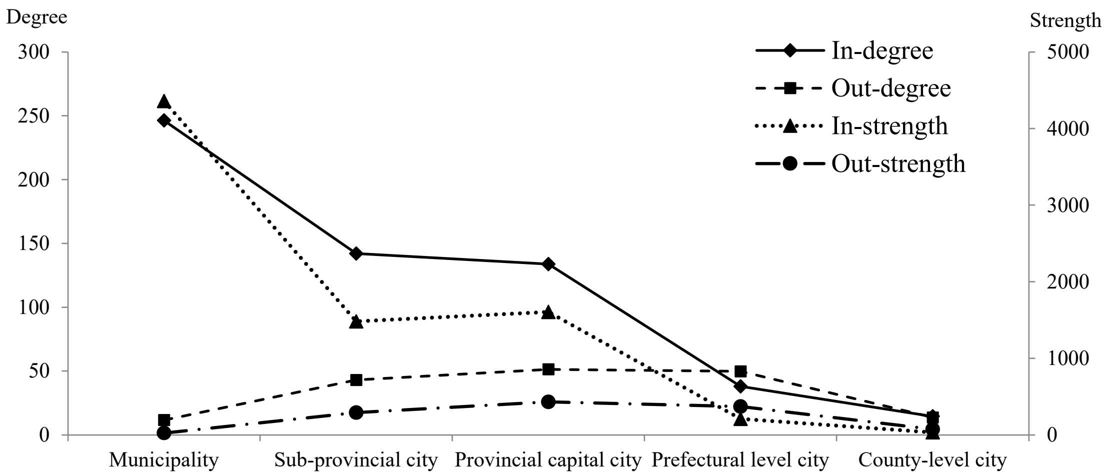

Figure 4. The changing trends of network characteristics in different types of cities.

Beijing, Shanghai, and Tianjin, the three municipalities directly under the central government, demonstrate significantly larger attraction ranges and magnitudes for rural populations compared to other cities. Conversely, their outflow of rural populations is minimal, indicating a strong tendency to absorb populations within the network. Sub-provincial cities and other provincial capitals exhibit relatively similar indicators, with their capacity to attract rural populations exceeding their outflow in both range and size.

In contrast to the above-mentioned city categories, other prefecture-level cities in the network exhibit a reversal in population flow characteristics. The outflow range and size of rural populations surpass the inflow, indicating a radiating tendency in population movement. County-level cities, although predominantly characterized by outflowing populations, generally have smaller indicators, placing them in a relatively weaker position within the network.

It is noteworthy that Chongqing, despite attracting a substantial number of migrants from rural populations, also possesses the highest node out-degree and out-strength in the entire network. This overall pattern suggests a radiating tendency in population movement, presenting a different network characteristic compared to the other three municipalities directly under the central government.

4.3. City Cluster Detection of Rural Population Migration

As depicted in Figure 5, through iterative calculations, the 363 cities in the network eventually converge into seven major clusters, each exhibiting an average clustering coefficient around the level of 0.300. Within these clusters, rural population migration relationships among cities are closely interconnected. The overall modularity reaches 0.468, indicating a high-quality partitioning of clusters. The identified clusters are as follows: G1, primarily consisting of cities in the northeastern and Inner Mongolia regions; G2, dominated by cities in the North China region; G3, comprising cities in the regions of Jiangsu, Zhejiang, Anhui, and northern Jiangxi; G4, centered around cities in the South China region, including Guangdong, Guangxi, Hunan, and Hainan; G5, primarily composed of cities in the northwest region; G6, centered around cities in the southwest region; and G7, formed by cities in the Hubei and Fujian provinces.

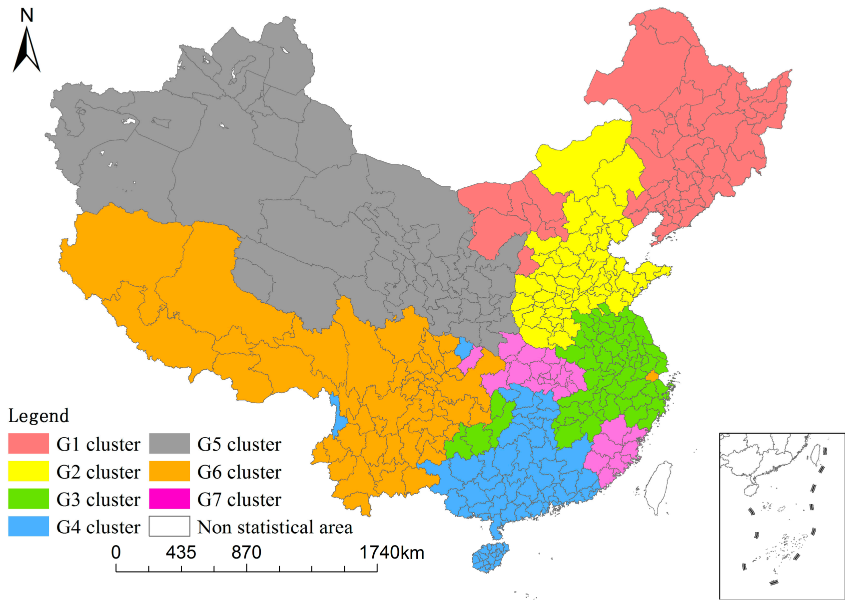

Figure 5. City cluster division of rural population migration.

Due to variations in city importance, each cluster exhibits distinct structural characteristics (see Table 3). Remarkably, although the iterative calculation process does not explicitly consider geographic elements, the convergence results clearly demonstrate significant regional clustering within each cluster. This suggests that cities in close proximity tend to form regional clusters of population movement due to strong correlations influenced by economic, cultural, and other factors.

Table 3. Structure of each cluster and important cities.

Cluster / Importance	G1	G2	G3	G4	G5	G6	G7
>1.00	/	Beijing	Shanghai	/	Yulin	Chongqing	/
	/	Tianjin	Hefei	/	/	/	/
>0.85	Changchun	Shijiazhuang	Fuyang	/	/	Chengdu	Quanzhou
	/	/	Wenzhou	/	/	/	/
>0.70	Hohhot	Zhengzhou	Nanchang	Changsha	Xining	Kunming	Wuhan
	Harbin	Zhoukou	Ningbo	Nanning	Xian	Lhasa	/
	/	/	Hangzhou	/	Lanzhou	Zunyi	/
	/	/	/	/	/	Guiyang	/
Average clustering coefficient	0.311	0.291	0.301	0.300	0.307	0.327	0.307
Number of cities	50	55	57	68	56	50	27

Note: "/" indicates that the cluster lacks cities of corresponding importance.

4.3.1. Four-Tier Structure Mode: "North China", "Jiangsu-Zhejiang-Anhui-Jiangxi", and "Southwest China" Clusters

In the G2 "North China" cluster, the node importance of Beijing and Tianjin significantly surpasses that of other cities, reaching 1.727 and 1.600, respectively. Additionally, their node symmetry degrees are 4457.15 and 3947.22, respectively, indicating a pronounced tendency for population absorption. Shijiazhuang and Zhengzhou also exhibit relatively high node importance, with values of 0.995 and 0.824, respectively. However, their symmetry degrees are lower at 427.60 and 1025.21, respectively, indicating a considerable gap in population absorption capabilities compared to the former two cities. Conversely, Zhoukou and Zhumadian stand out in this cluster as cities with a significant tendency for population radiation, with symmetry degrees of −1706.44 and −1069.04, respectively.

Shanghai and Hefei emerge as the central cities in the G3 "Jiangsu-Zhejiang-Anhui-Jiangxi" cluster, with node importance values of 1.712 and 1.186, respectively. However, Shanghai exhibits a node symmetry degree of 4450.02, while Hefei's symmetry degree is only 37.78. Fuyang, Wenzhou, and Nanchang all have node importance values above 0.800. Notably, Fuyang demonstrates a distinct tendency for population radiation, with a symmetry degree of −1279.18, while Wenzhou and Nanchang do not show a clear tendency for population movement. Furthermore, cities in the Jiangsu and Zhejiang province, such as Suzhou, Wuxi, Nanjing, Ningbo, and Hangzhou, exhibit strong tendencies for population absorption. In contrast, cities with a pronounced tendency for population radiation are mainly located in the central region, including Bozhou, Xinyang, and Shangqiu.

In the G6 "Southwest China" cluster, Chongqing stands out with a node importance of 3.300, indicating highly active rural population movement. The city exhibits a symmetry degree of −266.42, suggesting a weak tendency for population radiation. Chengdu has node importance and symmetry degree values of 0.933 and 269.33, respectively. Lhasa, Linzhi, and Kunming are cities within this cluster that demonstrate the most significant population absorption tendencies, with symmetry degrees of 1256.69, 1101.09, and 1083.69, respectively. Conversely, cities with a more pronounced tendency for population radiation in this cluster are Nanchong and Guang'an, with symmetry degrees of −955.09 and −940.42, respectively.

Overall, the G2, G3, and G6 clusters exhibit significant progressive hierarchical structures. Cities such as Beijing, Shanghai, and Chongqing have node importance values exceeding 1.000, occupying strong core positions within their respective clusters. Cities like Shijiazhuang, Fuyang, and Chengdu have node importance values exceeding 0.850, playing roles as secondary core cities. On the other hand, cities such as Zhengzhou, Nanchang, and Kunming have a weaker core role within their respective clusters, with node importance values at the 0.700 level. The transition of node levels within each cluster follows an orderly pattern, presenting a four-tier structure of "strong core cities—secondary core cities—weak core cities—edge cities".

4.3.2. Three-Layer Structure Mode: "Northeast China and Inner Mongolia" and "Hubei-Fujian" Clusters

In the G1 "Northeast China and Inner Mongolia" cluster, Changchun, Hohhot, and Harbin emerge as the central cities, with node importance values of 0.884, 0.842, and 0.788, respectively, significantly higher than other cities in the cluster. Specifically, Hohhot exhibits a symmetry degree of 660.91, indicating a certain degree of population absorption tendency, while Changchun and Harbin have symmetry degrees of only 153.46 and 98.49, respectively. Within this cluster, Shenyang and Dalian have symmetry degrees of 914.88 and 780.04, respectively, making them the cities with the most significant population absorption tendencies. On the other hand, Ulanqab, Suihua, and Qiqihar exhibit a more pronounced tendency for population radiation, with symmetry degrees of −1158.89, −1084.60, and −982.15, respectively.

The G7 "Hubei-Fujian" cluster is the smallest in scale within the rural population migration network. Quanzhou and Wuhan are cities with relatively high node importance in this cluster, with values of 0.889 and 0.776, respectively. Regarding population movement tendencies, Xiamen has a symmetry degree of 1750.18, making it the city with the most significant population absorption tendency in this cluster. Following are Wuhan and Fuzhou, with symmetry degrees of 810.35 and 513.50, respectively, indicating notable population absorption tendencies. On the other hand, Xiaogan and Dazhou are cities in this cluster with the most significant population radiation tendencies, having symmetry degrees of −688.65 and −674.95, respectively.

Overall, both the G1 and G7 clusters exhibit a relatively orderly transition of node levels among cities. However, both clusters lack strongly central cities with high node importance, with only Changchun and Quanzhou serving as secondary core cities within their respective clusters. Hohhot, Harbin, and Wuhan hold weaker core city positions. Both clusters present a three-tier structure of "secondary core cities—weak core cities—edge cities".

4.3.3. "Fault Type" Three-Tier Structural Mode: "Northwest China" Cluster

In the G5 cluster, Yulin has the highest node importance, reaching 1.094, making it the leading city in this cluster. However, its population movement tendency is not clear, with a symmetry degree of only −14.14. The provincial capitals of Xining, Xi'an, and Lanzhou closely follow, with node importance values of 0.795, 0.782, and 0.780, respectively. Only Xi'an exhibits a strong population absorption tendency, with a symmetry degree of 900.46. In this cluster, Urumqi, Yinchuan, and Haixi are the cities with the most significant population absorption tendencies, with symmetry degrees of 1538.89, 1240.20, and 1033.44, respectively. Conversely, Haidong and Guyuan are cities with a more pronounced population radiation tendency, with symmetry degrees of −636.24 and −630.23, respectively.

Overall, there is a considerable disparity in node levels among cities in the G5 cluster. Yulin's node importance is significantly higher than that of other cities, making it a strong core city in this cluster. Xining, Xi'an, and Lanzhou play a role as weak core cities, resulting in a "fault type" three-tier structure of "strong core cities—weak core cities—edge cities" in this cluster.

4.3.4. Double-Tier Structure Mode: "Guangdong-Hunan-Guangxi-Hainan" Cluster

Changsha and Nanning are cities with relatively high node importance in the G4 cluster, with values of 0.838 and 0.835, respectively. Both cities exhibit a certain degree of population absorption tendency, with symmetry degrees of 683.92 and 408.10, respectively. Additionally, cities in the Greater Bay Area, such as Dongguan, Shenzhen, Guangzhou, and Foshan, show a pronounced population absorption tendency, with symmetry degrees around 1500.00. On the other hand, Shaoyang is the only city in this cluster with a more significant population radiation tendency, having a symmetry degree of −991.19.

Overall, the G4 cluster is characterized by a relatively moderate node level. It only has two weak core cities, Changsha and Nanning, and the centripetal force among cities in the cluster is not high. The rural population shows a higher degree of dispersion in choosing migration paths within the cluster, resulting in a double-tier structure of "weak core cities—edge cities" in the cluster.

5. Discussion

5.1. Summary of Research Results and Validation of Hypotheses

Due to variations in research perspectives, spatial scales, and geographical scopes, scholars have produced differing results in the study of rural population migration. In terms of regional disparities in rural population migration, this study observes that cities in the eastern region remain the primary gathering areas for rural migrants, accommodating 39.28% of the rural population in the migration network, with a majority originating from inter-regional migrations. In contrast, the central region serves as the primary source of rural outmigration, with 36.05% of the rural population in the network departing from this area, and over half moving to other regions. These findings align with the results of studies by scholars such as Liu [46], confirming the viewpoint that economically developed coastal areas in China have strong population suction capabilities and supporting the Hypothesis 1 proposed in this paper. Since the 1990s, coastal cities in eastern China have seized historical opportunities stemming from early opening-up policies and advantageous geographical locations. They actively embraced and developed a large number of labor-intensive industries from the international arena, laying a solid foundation for the robust growth of the secondary and tertiary sectors in the region. Subsequently, the central government of China established free trade zones in eastern coastal areas such as Shanghai, Guangdong, Zhejiang, and Shenzhen to facilitate exports and attract foreign investors. This series of strategies has elevated both the economic development level and the number of employment opportunities available in eastern coastal cities far beyond those in inland cities. Consequently, this has attracted a significant influx of rural migrants from inland areas seeking jobs and higher incomes, thereby influencing the migration patterns of China's rural population.

However, in contrast to previous studies that did not differentiate between urban and rural migrants, this study reveals that although western cities are active in both the inflow and outflow of rural populations, there is relatively little population migration between the western region and other areas. About 28.54% of rural migrants in the network move within the western region, while the proportion of cross-regional migration in and out is only 7.46% and 9.37%, respectively. The findings above deviate from the impression that economically underdeveloped western cities are significant sources of population outflow, indicating that the migration characteristics of rural populations are not entirely consistent with those of general floating populations and demonstrating their unique attributes. The reason for this may be that, with the recent industrial upgrading and inland migration of industries from the eastern region, the demand for human resources in the east has shifted from labor-intensive to intelligence-intensive. Influenced by increased employment thresholds and the westward shift of industries, rural migrants in the western region have gradually begun to return to their hometowns, and working in nearby cities within the region has become a more feasible choice than migrating to the distant eastern region [23].

In terms of city differences in rural population migration, an analysis of the population absorption range, scale, and throughput characteristics of various cities reveals significant variations in the roles played by cities of different administrative levels within the rural population migration network. Municipalities directly under the central government such as Beijing, Tianjin, and Shanghai exhibit significantly larger absorption ranges and scales for rural populations compared to other cities in the network. Moreover, they demonstrate a distinct population absorption tendency in terms of throughput characteristics. Similarly, sub-provincial and provincial capital cities share similar features. On the other hand, ordinary prefecture-level cities and county-level cities generally lack the ability to absorb rural populations. They predominantly serve as sources of outbound population movements, indicating a population radiation tendency. These findings align with research results from scholars such as Long [26] and Mei [27]. The underlying reasons can be traced to China's current administrative system, where resource allocation in the process of socio-economic development is carried out hierarchically from top to bottom [47]. This distribution method gives higher-level cities advantages in policy support and production factor supply and subsequently positions them ahead in terms of industrial development, infrastructure construction, and the capacity to provide public services. The resulting advantages in employment opportunities, education and training, healthcare facilities, and elderly care services exert a strong appeal to migrant populations, closely linking the migration patterns of rural migrants to the administrative hierarchy of cities.

Detecting rural population migration relationships between different cities is a unique contribution made in this paper. Due to data limitations, this method has not been applied to research on rural population migration before. The results reveal that cities form seven major clusters in the population migration network, and rural population movements primarily occur within cities belonging to the same cluster, with relatively fewer interactions between clusters. This results in a significant phenomenon of interlocking among cities within the same cluster. It is noteworthy that cities within each cluster exhibit distinct spatial agglomeration characteristics, and the internal structures of different clusters vary. Some clusters display complex multi-layered structures, while others have relatively flat internal structures. The findings above substantiate Hypothesis 2 of this study. That is, even within the same country, rural population migration activities in different regions exhibit distinct characteristics, resulting in varying internal structures among different city clusters.

Additionally, Hypothesis 3 is also confirmed in this study. Economically underdeveloped small cities such as Fuyang and Zhoukou play a core node role comparable to large cities within the rural population migration network. However, their function within the network contrasts with that of large cities. Instead of attracting rural migrants, these small cities serve as significant sources of outward migration. Rural population migration is a multifaceted process fundamentally rooted in the alignment of industrial distribution and labor resources. For some small cities with dense agricultural populations, their relatively backward economic development hinders them from providing sufficient employment opportunities. Consequently, a considerable portion of the local rural population is compelled to migrate outward in search of better job prospects in more developed areas. It is precisely due to this unique circumstance that these distinctive small cities emerge as primary origins of rural migration. Thus, despite their lower economic development and smaller urban scale, these cities occupy crucial positions in the rural population migration network by virtue of their substantial outflow of rural migrants. This phenomenon underscores the diversity and complexity inherent in the rural population migration process, emphasizing the necessity for a deeper understanding and appreciation of the significance of these small cities within the migration network.

5.2. Analysis of the Causes of Rural Population Migration Network

The reasons for the formation of the migration network we observed may be complex and multifaceted. Rural migrants are not merely labor factors influenced by regional industrial structures and economic development levels [48]; they are also sentient beings with social relationships and cognitive abilities, inevitably influenced by cultural factors such as heritage and nostalgia [49]. The role of economic and cultural factors has been extensively evidenced in previous studies on the motivations of migrants in emerging countries [50–53].

As a production factor, the dense industrial distribution and higher economic level in developed regions can provide ample employment opportunities and higher income expectations for rural migrants. Given the low comparative returns in agriculture, this can strongly attract rural populations from relatively underdeveloped areas. However, the population capacity of any city is not unlimited. Excessive population concentration and industrial transformation/upgrading can lead to the screening of labor resources, resulting in unemployment [54–56]. Thus, although higher economic levels in cities tend to attract the concentration of rural populations, the "excess" population that cannot be fully employed in developed cities still needs to change its migration destination. These individuals may seek employment opportunities in relatively less developed cities, contributing to the multi-tier structures observed in clusters like G2, G3, and G6.

Furthermore, as sentient beings with social relationships, the migration decisions of rural migrants are inevitably influenced by "soft factors" such as lifestyle habits and cultural environments [57]. China is a nation with diverse ethnicities and cultures, leading to differences in the main cultures among regions. Rural populations in different areas may exhibit disparities in diet, housing, language, and social interaction, creating obstacles to cross-regional migration. This cultural diversity prevents rural populations from unilaterally choosing the most developed regions as their migration destinations. Moreover, the social fabric, characterized by the connections between friends and family, also significantly influences people's migration decisions. According to D. S. Massey's theory of migration networks [58], along with the formation of population migration networks, an information dissemination network consisting of social relationships such as relatives, fellow villagers, and friends is also formed. This network serves as a primary source of reference for potential migrants when making migration decisions. Therefore, when rural populations make migration decisions, they can obtain destination-related information from friends or family who have already migrated, such as job opportunities, salary levels, living conditions, etc. This can help them make wiser choices, deciding whether they should migrate and where they should migrate to. Moreover, social relationships can provide emotional and resource support for migrants [59]. Migrants can rely on social ties to obtain financial assistance, accommodation, and other forms of help, effectively reducing their migration risks and highlighting the crucial role of social relationships in the migration decision-making process. The findings from studies conducted by scholars such as B. Bilecen [60] have corroborated these viewpoints.

In addition, having feasible transportation options is fundamental for rural populations to migrate between regions. This encompasses the development of railway and road networks, as well as the construction of other transportation infrastructure. Effective transportation infrastructure can significantly improve accessibility between regions, thereby influencing the migration decisions and behaviors of rural populations. As such, transportation infrastructure may also play a crucial role in contributing to the observed rural migration patterns. The findings of scholars such as O. Kotavaara [61] also support this viewpoint. Since the beginning of the 21st century, China has constructed over 170,000 km of expressways and more than 40,000 km of high-speed railways, significantly enhancing the convenience of travel for its residents. However, constrained by geographical factors, most of these transportation infrastructure developments have been concentrated in the plains of China's central and eastern regions. This has led to closer economic and geographical ties between cities in these regions. Rural populations in these areas have easier access to job information in cities, more options for transportation, and lower time costs for migration. Therefore, as reflected by the migration patterns observed in clusters G2, G3, G4, and G7, rural migration between the central and eastern regions of China is prevalent. A substantial portion of the rural population from the central regions migrates toward the developed coastal areas in the east. On the contrary, western regions of China are characterized by mountainous and hilly terrain. Although there are highways and high-speed railways connecting the central and western regions, the number of them remains relatively limited, and transportation capacity is constrained. This could be one of the reasons why rural population migration from the western regions to the central and eastern regions of China is comparatively less common.

Moreover, spatial distance is a crucial factor influencing migration decisions. "Leaving one's hometown" is inherently a risky behavior. The farther the migration distance and the greater the cultural differences, the higher the corresponding migration risk [62]. Additionally, any developed region has a range for economic radiation to its surroundings.

Despite the convenience of long-distance migration facilitated by transportation means like high-speed rail, migration costs and cultural differences do not necessarily decrease. Therefore, while developed regions can offer higher employment opportunities and income expectations, rural populations tend to balance spatial distance and economic aspirations. They are inclined to migrate to nearby relatively developed areas to reduce migration risks and the cost of leaving home [63]. This is the reason why clusters like G1 and G7, although lacking strong central cities, can still form clusters with relatively flat hierarchical structures during the rural population migration process, displaying significant regional agglomeration characteristics.

5.3. The Enlightenment Gained from This Study

Based on the discussion above, aiming to achieve the goal of "revitalizing rural areas", the governments of areas experiencing population outflows can consider focusing on developing the county-level economy as a key breakthrough. They can actively undertake transferring industries from developed regions and facilitate the downward shift of urban industries to small towns. Additionally, they can promote industry decentralization appropriately, effectively increasing job opportunities and income levels in small towns within the county. This approach aims to attract rural migrants for local employment and entrepreneurship, stimulate the development of local rural economies, and gradually drive the comprehensive development of rural areas and agriculture.

By actively participating in the transfer of industries from developed areas, local governments in the migration source regions can create a favorable environment for economic development in the county, providing more job opportunities and higher income prospects. This strategy not only encourages rural migrants to seek employment and entrepreneurship in nearby small towns but also contributes to the overall development of local rural economies. Furthermore, promoting industry decentralization and supporting the development of small towns within the county can address the challenges associated with excessive population concentration in large cities. It helps distribute economic development more evenly across different regions, preventing the negative impacts of overpopulation on urban infrastructure, public services, and the environment. In summary, prioritizing the development of the county-level economy, actively undertaking the transfer of industries, and promoting the decentralization of urban industries to small towns can effectively retain human resources in rural areas, creating a conducive environment for sustainable agricultural development and the local citizenization of rural migrants.

It is crucial to note that the suggestions provided above are not only applicable to China but also hold significant implications for many developing countries worldwide, particularly emerging nations such as Vietnam, India, and Indonesia. These countries, the same as China, have also adopted an unbalanced economic development strategy and are currently undergoing rapid industrialization and urbanization processes, resulting in the widening gap in development levels between regions and the emergence of a large number of rural migrants. Therefore, under such similar national conditions, the conclusions and suggestions drawn from analysis and discussion in this article are equally effective for these developing countries and can provide them with references for scientifically guiding rural population migration and promoting rural development.

Through the findings and discussion presented above, this paper made new contributions to the migration literature in the following ways. First, this paper clarified that the migration characteristics of rural populations differ from those of general migrant populations, emphasizing the need for differentiated research. Second, this paper discovered that even within the same country, population migration exhibits regional characteristics, with different regions displaying different population migration features. Third, this paper demonstrated that small cities also play a significant role in population migration process, warranting attention in future research. Finally, the findings of this paper are of reference significance not only to China but also to many emerging countries with similar national conditions in the world. At the same time, this paper also provides some enlightenment for future research from a methodological perspective. The network analysis method employed in this paper not only allows for the analysis of migrants' spatial distribution like traditional methods but also enables exploration of internal features of population migration, such as the core cities, city clusters, the scale and direction of population migration between different regions, etc. The application of this method can lead scholars to new discoveries that were previously unattainable.

6. Conclusions

The long-term substantial presence of rural migrants is a fundamental characteristic of many developing countries. In this context, analyzing the rural population flow among various cities holds significant importance for scientifically guiding rural population movements and promoting the development of rural areas. Based on this perspective, this paper conducts an analysis of the inter-city migration patterns of rural migrant population from the viewpoint of urban networks, yielding the following conclusions:

(1) There is a significant spatial autocorrelation in both the inflow and outflow directions of rural populations. The migration patterns of rural populations among cities exhibit notable spatial clustering characteristics and spatial dependence effects. There are commonalities in the rural population flow between neighboring cities, showing a regional clustering tendency in geographical space. Moreover, distinct spatial patterns emerge in the inflow and outflow directions, reflecting a "west cold, east hot" trend and an "external cold, internal hot" pattern, respectively.

(2) Cities of different administrative levels exhibit distinct node characteristics in the migration network. Municipalities directly under the central government, sub-provincial cities, and provincial capitals demonstrate a pronounced tendency to absorb rural populations, while ordinary prefecture-level cities and county-level cities primarily radiate rural populations outward. Regarding regional disparities, cities in the eastern region have larger sizes and scopes for absorbing rural populations. In the central region, cities predominantly act as sources for cross-regional migration. Rural populations in the western region mainly engage in intra-regional migration, and in the northeastern region, rural population migration is not active.

(3) Cities across China have coalesced into seven major clusters within the rural population migration network. Intra-cluster cities exhibit closely knit relationships in terms of population movements, with municipalities directly under the central government and provincial capitals holding significant positions and roles as regional hubs in each cluster. The differing importance levels of cities contribute to distinct structural characteristics within each cluster. Factors such as economic dynamics, cultural influences, and industrial layouts collectively drive the emergence of these structural patterns.

(4) The driving forces attracting the concentration of rural populations include robust infrastructure, educational facilities, healthcare services, and a well-developed secondary and tertiary sector. Aiming to achieve the goal of "revitalizing rural areas", governments in areas experiencing population outflows might consider focusing on county-level city development. This involves actively undertaking and optimizing industrial layouts to attract rural migrants for local employment and urbanization, thereby catalyzing innovation in rural industries and promoting overall urban–rural integration.

Certainly, it is also important to note that the National Health Commission's 2017 China Migrants Dynamic Survey data, utilized in this study, have been instrumental due to their extensive coverage and large sample size, facilitating the clear construction and analysis of rural migration networks. Currently, CMDS has opened access to the 2009–2018 data. However, limitations arise from the remaining years of the open-access dataset. In the data from 2009 to 2016, detailed information on respondents' migration paths was not extensively collected. In the 2018 data, the migration information was withheld due to policy. This impedes a longitudinal analysis of the evolution of rural migration patterns.

Therefore, further research on this aspect awaits the gradual release of subsequent years' data or the implementation of a new round of surveys on migrant populations.

Author Contributions: Conceptualization, Y.Z. and H.C.; methodology, Y.Z. and T.F.; software, Y.Z. and T.F.; validation, Y.Z. and T.F.; formal analysis, Y.Z.; investigation, Y.Z.; resources, Y.Z.; data curation, Y.Z. and H.C.; writing—original draft preparation, Y.Z.; writing—review and editing, Y.Z. and T.F.; visualization, Y.Z. and T.F.; supervision, H.C.; project administration, H.C.; funding acquisition, H.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Key Project of National Social Science Foundation of China, grant number 18AZD023.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of these data. Data were obtained from the National Health Commission of China and are available from the authors with the permission of the National Health Commission of China.

Conflicts of Interest: The authors declare no conflicts of interest.

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