Analysis of Academic Cooperation and Influencing Factors in the Guangdong-Hong Kong-Macao Greater Bay Area Based on Complex Networks

Jiong'en Xiao, Fan Ni Yang

Abstract

Based on the cities of the Guangdong-Hong Kong-Macao Greater Bay Area as fundamental nodes, this study collects data from the Web of Science (WoS) with research themes including information technology, life sciences, biological sciences, and physical sciences. It constructs three regional academic cooperation complex networks from a multi-regional perspective and provides development strategies and suggestions to promote academic cooperation in the Greater Bay Area based on the analysis results. By using indicators such as degree distribution, PageRank, average path length of the network, and closeness centrality, this study analyzes the academic cooperation situation in the Guangdong-Hong Kong-Macao Greater Bay Area and identifies the influencing factors of academic cooperation in the Greater Bay Area, including culture, scientific research, economy, and population, based on the regional innovation theory framework. The study finds that the academic cooperation network of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area shows a clear structure of core-periphery and has small-world characteristics. Guangzhou, Hong Kong, and Shenzhen are the cores of academic cooperation in the Greater Bay Area. Guangzhou leads Shenzhen in domestic cooperation, while Shenzhen slightly outperforms Guangzhou in international cooperation. It is also found that geographical distance is no longer a factor hindering academic cooperation.

Keywords Guangdong-Hong Kong-Macao Greater Bay Area; Complex Network; Network Degree; Regional Innovation

1. Introduction

The concept of the Guangdong-Hong Kong-Macao Greater Bay Area was first proposed in 2005 in the "Pearl River Delta Urban Agglomeration Coordinated Development Outline (2004~2020)", referring to the "9+2" city cluster composed of the nine cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Zhongshan, Dongguan, Huizhou, Jiangmen, and Zhaoqing in Guangdong Province, and the two Special Administrative Regions of Hong Kong and Macao. On July 1, 2017, the National Development and Reform Commission and the governments of Guangdong, Hong Kong, and Macao signed the "Framework Agreement on Deepening Guangdong-Hong Kong-Macao Cooperation to Promote the Construction of the Greater Bay Area", marking the official launch of efforts to build the Guangdong-Hong Kong-Macao Greater Bay Area into a world-class bay area and city cluster [1]. The agreement proposes to actively build a new open economic system, create high-level open platforms, gather innovative resources, improve the regional collaborative innovation system, and carry out innovation and technological cooperation.

Currently, many scholars and experts have discussed issues such as technological innovation in the Guangdong-Hong Kong-Macao Greater Bay Area and asset allocation under the current macro situation [2]. Scholars believe that technological innovation will be the main theme of the Greater Bay Area's future development, and there is still a need to address the issue of insufficient depth in scientific research cooperation. There is room for further deepening in terms of complementary advantages and deep-level technological cooperation. Compared to several other important bays in the world (San

Francisco, Tokyo, New York), the Guangdong-Hong Kong-Macao Greater Bay Area still lags behind in terms of scientific research achievements. In the future, academic cooperation between the main cities of the Greater Bay Area and mutual promotion will be the main direction for development.

How the cities in the Guangdong-Hong Kong-Macao Greater Bay Area cooperate academically and how to further promote academic cooperation in the Greater Bay Area have become one of the key research focuses.

2. Literature Review and Approach to Problem Solving

Scholars have conducted research on the Guangdong-Hong Kong-Macao Greater Bay Area from various aspects such as technology, humanities, and economy, and from multiple different perspectives, sparking a wave of research on the Greater Bay Area. For instance, Cai Chimeng [3] studied the strategic significance and challenges faced by the construction of the Greater Bay Area, and Zhao Xiaobin et al. [4] explored the development strategy and path of the Greater Bay Area in conjunction with its current situation, but these studies mainly focused on policy exploration. With in-depth research, scholars have attempted to use various algorithmic models for quantitative research on the Greater Bay Area. Chen Yan et al. [5] conducted an empirical analysis of the industry-specific location entropy and the grey correlation degree between cities and industries in the Greater Bay Area based on data from 19 industries in 11 cities of the area. Qin Yanhua et al. [6] used the Analytic Hierarchy Process to analyze the innovation capabilities and rankings of the 11 cities in the Greater Bay Area, pointing out the issues faced by the technological collaborative innovation of the city cluster in the Greater Bay Area and proposing countermeasures and suggestions. However, there seems to be no research on academic cooperation in the Greater Bay Area with cities as the main body in the literature. To fill this gap, this study has made three considerations: 1) Considering that the Greater Bay Area includes Hong Kong and Macao, the research data collection is defined to cover the SCI and SSCI in the WOS database; 2) Previous academic cooperation research generally takes schools or countries as units, while this study takes the cities of the Greater Bay Area as the main body to analyze academic cooperation; 3) There is a big difference in academic cooperation among various disciplines, so information technology, life sciences, biological sciences, and physical sciences, which are more representative, are selected as research disciplines.

The study of academic cooperation networks is a fundamental task. Only by studying the relationships and the degree of closeness can we further study the factors influencing cooperation, and then propose strategies and suggestions to promote academic cooperation. The perspectives of previous scholars' research can be divided into countries, provinces, schools, or scholars, such as: Xu Xin [7] and others used WOS literature data to analyze and study the evolution of the international scientific research cooperation network under the funding of the National Science Foundation with countries as the main body; Wang Zhigang and Qiu Changbo [8] analyzed the evolution of the SCI paper cooperation network between provinces in mainland China with provinces as the main body; Dong Yanbang and Liu Li [9] studied the evolution of the institutional cooperation network of high-level papers in Chinese universities with schools as the main body; Zhu Yunxia [10] studied the scholar association model based on co-authorship and co-citation relationships from the perspective of scholars. Calero et al. [11] studied the cooperation of scholars in jointly publishing medical papers, and then studied the cooperative relationships between various pharmaceutical factories. From this research, it is found that with the help of complex network analysis, deep cooperation of enterprises and even cooperation between regions can be excavated, which is conducive to finding the underlying factors and proposing strategies and suggestions. Barber et al. [12] studied the cooperative relationships between European

research institutions, providing a new perspective on the overall and local structure of R&D cooperation within Europe with the characteristics and technical indicators of complex networks. In summary, when conducting academic cooperation network analysis, it is particularly important to choose the main body, and at the same time, reasonable network indicators must be selected to explore the deep-seated factors of cooperation between the main bodies, and then propose strategies and suggestions.

3. Analysis of Inter-City Academic Cooperation Based on Complex Networks

3.1 Research Approach

The academic cooperation among cities in the Guangdong-Hong Kong-Macao Greater Bay Area presents a complex network of relationships. Taking information technology, life sciences, biological sciences, and physical sciences as examples, this study examines the collaboration on high-quality papers. By selecting academic achievements in these disciplines, a cooperation network for each node city is constructed. This paper uses high-quality academic papers from the WOS database as the data source for the study, identifying collaborations based on multiple affiliations listed in the papers. If an academic paper has two affiliations, with City A being the city of the first affiliation and City B being the city of the second affiliation, then an academic cooperation relationship between City A and City B is identified. If an author is affiliated with multiple addresses, to ensure clarity of analysis and representativeness of the paper's achievements, the first affiliation is taken as the subject of study. By collecting and analyzing a large number of academic papers in information technology, life sciences, biological sciences, and physical sciences from the WOS database, a cooperation network model between cities can be constructed. Three different network models are used to measure the academic cooperation among the 11 cities in the Greater Bay Area. The overall approach of this study is shown in Figure 1.

Newman [13] proposed solving specific problems in research through the structure and function of complex network models, and the construction of the model is implemented using the Gephi [14] software. Through data processing, the specific models constructed in this paper include: Model (1) the high-quality paper academic cooperation network model between the 11 cities in the Greater Bay Area; Model (2) the high-quality academic cooperation network model between the 11 cities in the Greater Bay Area and major domestic cities, to further analyze the domestic academic cooperation of the 11 cities; Model (3) the high-quality paper academic cooperation network model between the 11 cities in the Greater Bay Area and major countries around the world, mainly to analyze the international academic cooperation of the 11 cities.

Some important indicators can characterize the network properties of the complex network model. The specific city characteristic indicators of the academic cooperation network include degree distribution [15], pageRank [16]. The overall characteristic indicators of the academic cooperation network include average path length [17], closeness centrality [18], and clustering coefficient [19]. Using these indicators and measurement methods, a new perspective on the study of the city's academic cooperation can be carried out, the specific content is as follows.

1) Specific Urban Characteristic Indicators of the Academic Cooperation Network.

Degree distribution and pageRank are metrics that can indicate the role, status, or influence an academic entity in a city holds within the entire network. In the context of mathematical graph theory, the degree of a node within a network is the count of edges that connect to the node. Within an academic cooperation network, this degree signifies

the number of collaborative ties a particular city has with others. pageRank, a significant node importance analysis tool in academic cooperation network studies, posits that a node's importance is heightened by its greater number of connections to other nodes. The pageRank is calculated using a formula that considers the set of nodes connected to a given city, the number of connections each of those nodes has, the total number of nodes in the network, and a damping factor that is historically determined by analysis experience, often around 0.85 [16].

2) Overall Characteristic Indicators of the Academic Cooperation Network.

The average path length and closeness centrality indicators reflect the tightness and degree of networking in academic cooperation among the cities within the academic cooperation network. In the Greater Bay Area city cluster's undirected network of academic achievements, the average shortest distance between any two nodes is represented by 'l', indicating the typical separation between nodes. The formula for calculating 'l' involves the shortest distance from one node to another within the network. A lower 'l' value in the Greater Bay Area's academic cooperation study suggests more frequent cooperation among the network's nodes.[17].

Closeness centrality is a measure of how near a node is to all other nodes, calculated by summing the distances from the node to every other node. A smaller sum indicates a shorter average path to all other nodes, signifying closer proximity. This concept, as defined by Freeman, is the reciprocal of the summed distances, with the formula excluding the node in question. The resulting closeness centrality value ranges from 0 to 1, where values nearing 1 suggest more intimate cooperation with other cities. Within the Greater Bay Area's academic cooperation network, a city node with a closeness centrality approaching 1 is engaged in closer academic collaboration with other cities. [18].

3.2 Data Processing

Analyzing the academic cooperation network of the Guangdong-Hong Kong-Macao Greater Bay Area from a multi-regional perspective involves comparing data from three types of networks: the internal city academic paper cooperation network within the Greater Bay Area, the cooperation network built between the Greater Bay Area cities and major domestic cities, and the cooperation network constructed with major countries around the world. The study investigates the intrinsic mechanisms that characterize these networks.

Since the Guangdong-Hong Kong-Macao Greater Bay Area includes mainland cities as well as the two Special Administrative Regions of Hong Kong and Macao, the data source must ensure a unified statistical approach worldwide. Therefore, this study selects the SCI or SSCI academic papers from the WOS database for the years 2012-2019 as the data source. The search formula is entered into the WOS search system as follows: AD(Guangzhou OR Foshan OR Zhaoqing OR Shenzhen OR Dongguan OR Huizhou OR Zhuhai OR Zhongshan OR Jiangmen OR Hongkong OR Macau) AND Su=(Information Technology OR Biomedicine OR Physical Sciences OR Life Sciences) AND Py=(2012-2019). The search is conducted with the 11 cities as the main subject, and the sample data includes 8,403 SCI or SSCI papers themed on information technology, life sciences, biological sciences, and physical sciences. Since the paper data downloaded from the WOS includes dozens of fields such as title, authors, author affiliations, abstract, references, and funding projects, it is necessary to extract the city data of interest to this study. The specific data processing flow is shown in Figure 2.

Java programming is used for preliminary processing of the paper data, where the place name database comes from the National Place Name Information Network, including both Chinese and English names of places, which is the foundation of data preprocessing. The sample data extracted in step 2 as shown in Figure 2 is exemplified in Table 1. The information preprocessing includes extracting the title and author information, extracting the paper's address based on the place name database, and performing statistics.

According to the author information shown in Table 1, the city information can be extracted. Since the number of cities contained in the author information of each paper is variable, multiple judgments are required to complete the extraction. Special attention should be paid to the fact that in foreign language data, Jinan is displayed as "jinan," and Jinan University is also displayed as "jinan." Therefore, it is also necessary to make associated judgments to determine the province to which "jinan" belongs, and thus confirm the city. Through the statistical analysis of Step 4, the number of connections between different cities is obtained. According to the data structure of Gephi, the data table needed is processed and imported into Gephi to construct the academic cooperation network model of the cities within the Greater Bay Area (1) (see Figure 3), the academic cooperation network model between the Greater Bay Area and domestic cities (2) (see Figure 4), and the academic cooperation network model between the Greater Bay Area and major countries (3) (see Figure 5). Through the calculation and analysis of the paper data, the specific data of various indicators of models (1), (2), and (3) are obtained as shown in Table 2.

Based on the multi-centered network spatial structure of the knowledge innovation cooperation network research of the city cluster, it is proposed that the network nodes have a significant hierarchical nature [20]. Combined with the network characteristics of the Greater Bay Area, in model (1), Guangzhou (degree 10), Shenzhen (degree 10), and Hong Kong (degree 9) are the cores of the academic cooperation network, while Huizhou (degree 4), Zhaoqing (degree 3), and Jiangmen (degree 3) have less academic cooperation, and other cities are in between. By comparison, it can be found that there is a large gap in the academic development of various regions within the Guangdong-Hong Kong-Macao Greater Bay Area. This leads to an important question, what factors will affect the academic cooperation between regions?

Based on the structural heterogeneity of the global scientific research paper cooperation network and its adjacency mechanism, it is relatively evenly distributed, showing a pattern of "great dispersion, small concentration" [21]. According to the degree of each node city, the drawing result of the academic cooperation network between the Greater Bay Area and domestic cities is shown in Figure 4. In model (2), Guangzhou (degree 47), Shenzhen (degree 44), and Hong Kong (degree 42) are the three cities with the highest degree in the Greater Bay Area. The cities that are closely cooperating with these three major cities are Beijing (degree 44), Shanghai (degree 42), Nanjing (degree 41), Changsha (degree 41), Wuhan (degree 40), and Shenyang (degree 40). It can be seen that the main academic cooperation partners of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area are cities with many universities, scientific research institutions, strong scientific research strength, and developed economy. Some cities in the Greater Bay Area, such as Zhaoqing (degree 18) and Jiangmen (degree 11), have less cooperation with other cities. It can be found that Guangzhou, Hong Kong, and Shenzhen have a significant advantage in academic development and academic cooperation compared to other cities in the Guangdong-Hong Kong-Macao Greater Bay Area.

Based on the multi-scale research method of scientific cooperation patterns in complex networks [22], the research on the scientific cooperation situation in the

Guangdong-Hong Kong-Macao Greater Bay Area is conducted from multiple dimensions. Since international academic cooperation is relatively dispersed, the analysis is conducted on a country-by-country basis, and the academic cooperation network model between the cities of the Greater Bay Area and the main countries is depicted as shown in Figure 5. In Model (3), it can be observed that the main countries for academic cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area are the United States (degree 29), Australia (degree 29), the United Kingdom (degree 28), Canada (degree 28), France (degree 28), Germany (degree 27), Singapore (27), Japan (27), etc. It is evident that the international academic cooperation targets of the cities in the Greater Bay Area are primarily countries with a strong cultural heritage, stronger scientific research capabilities, and more developed economies.

3.3 Analysis of Paper Collaboration in the Guangdong-Hong Kong-Macao Greater Bay Area Based on Complex Networks

The impact of the centrality of knowledge sources on the efficiency of knowledge diffusion in the scientific cooperation network [23], the overall characteristics of the academic cooperation network are analyzed from the perspective of the integrity of complex networks. By studying the closeness centrality, it is found that the distribution of academic cooperation among the cities of Guangdong, Hong Kong, and Macao exhibits a three-tiered structure of "core-half-core-periphery" (as shown in Figure 6). By calculating and averaging the clustering coefficients of the three models, it is revealed that Guangzhou, Shenzhen, and Hong Kong belong to the core layer, with an average closeness centrality across the three models ranging from 0.8 to 1.0. The academic cooperation among Guangzhou, Shenzhen, and Hong Kong is the most intensive, and they also have extensive cooperation with other cities in the Greater Bay Area. Therefore, they play a significant leading role in the Greater Bay Area and exert a strong influence in the academic cooperation network. Foshan, Zhongshan, and Macao belong to the half-core layer, with an average closeness centrality across the three models ranging from 0.6 to 0.8, demonstrating a certain degree of influence in the academic cooperation network. Dongguan, Zhuhai, Huizhou, Zhaoqing, and Jiangmen are positioned in the periphery layer of the network, with an average closeness centrality across the three models ranging from 0.4 to 0.6, indicating relatively weaker academic cooperation capabilities.

By employing the clustering coefficient and pageRank to stratify the network, further examination of the overall network's density is conducted through the average path length and the number of model nodes. Model (1) consists of the 11 cities of the Guangdong-Hong Kong-Macao Greater Bay Area as nodes, with an average path length of 1.236. Model (2) includes the Greater Bay Area and major domestic cities, totaling 48 nodes, with an average path length of 1.355. Model (3) comprises the Greater Bay Area and major countries of the world, totaling 32 nodes, with an average path length of 1.264. It can be observed that as the number of city nodes increases, the average path length of the network also increases. Watts and Strogatz (1998) introduced the small-world network model [24] to describe the transition from a completely regular network to a completely random network. A small-world network possesses clustering characteristics similar to those of a regular network and also has a small average path length similar to that of a random network, typically with an average path length less than 6. The academic cooperation network of the Greater Bay Area, with an average path length of 1.23 to 1.35, is significantly less than 6, indicating that the academic cooperation of the Greater Bay Area with major domestic cities and major countries internationally is relatively tight.

By utilizing the degree and pageRank from complex networks to conduct specific urban characteristic studies of the scientific and technological network, and analyzing the

capabilities and roles of the major cities in the Bay Area in academic cooperation, the data can be standardized using the Z-score normalization method [25] to obtain Figure 7.

Based on the analysis and prediction of scientific cooperation relationships within community structures [26], the Guangdong-Hong Kong-Macao Greater Bay Area is a large community structure. By analyzing the aforementioned data, it can be seen from Figure 7 that in terms of domestic academic cooperation, Model (2) shows that Guangzhou has a degree of 47, which is slightly advantageous compared to Shenzhen's degree of 44. In terms of international academic cooperation, in Model (3), Shenzhen's degree of 31 is slightly advantageous compared to Guangzhou's degree of 30. Whether it is international or domestic academic cooperation, in Model (2), Guangzhou (degree 47), Shenzhen (degree 44), and Hong Kong (degree 42) currently have a clear advantage over other cities in the Greater Bay Area. Models (1 to 3) show that the academic cooperation capabilities of Guangzhou, Shenzhen, and Hong Kong are already at a relatively close level. By examining the cooperation network between cities, based on the degree in the network, the factors influencing the cooperation network between cities can be verified, and suggestions for promoting academic cooperation between cities can be made.

4. Analysis of Factors Influencing Academic Cooperation Relationships between Cities in the Guangdong-Hong Kong-Macao Greater Bay Area and Domestic Cities

4.1 Research Hypotheses

Based on the multi-factor driven domain knowledge network evolution model [27], combined with the academic cooperation data obtained from the analysis of complex networks in the previous text, serves as the basis for the analysis of factors influencing academic cooperation between cities in the Guangdong-Hong Kong-Macao Greater Bay Area. On this basis, the factors influencing the cooperation network are analyzed based on the regional innovation system theory. The theory of regional innovation systems mainly originates from the theory of national innovation systems. Freeman, based on social practice and surveys, proposed the concept of the national innovation system in 1988, defining it as "a network of various institutions in the public and private sectors within a sovereign state, whose activities and interactions promote the development, introduction, improvement, and diffusion of new technologies and organizational patterns" [28], emphasizing the interplay between the main elements of the system. On this basis, Cooke, by analyzing the rootedness and network nature of regional cooperation, proposed the concept of regional innovation systems, which are mainly composed of regional organizational systems such as higher education institutions that are geographically divided and related [29], and also include factors such as population, economy, culture, and geography. Suggestions for promoting urban academic cooperation are proposed based on the current situation and future development trends of scientific cooperation [30]. Based on the above theoretical foundations, the factors influencing the academic cooperation relationship between cities in the Guangdong-Hong Kong-Macao Greater Bay Area and domestic cities are analyzed as follows.

The number of universities a city has is one of the important characteristics of the city's cultural level and also an important reflection of its scientific research capabilities. If a city has a large number of universities, then the scientific research strength of that city is obviously strong. Therefore, it can be inferred that the city's academic cooperation capabilities are also strong. Hence, Hypothesis 1 is proposed.

H1: The number of universities a city has is positively correlated with academic cooperation between cities.

The number of scientific research institutions and the number of scientific research personnel are one of the important indicators of a city's research capabilities. If a city has a certain number of scientific research personnel, it is likely to better cooperate with scientific research personnel from other cities, and thus more likely to jointly conduct research and publish papers. If the number of universities in a city reflects its cultural heritage, then the number of national key laboratories in a city reflects its scientific and technological strength. Therefore, Hypotheses 2a and 2b are proposed.

H2a: The presence of national key laboratories in a city is positively correlated with academic cooperation between cities.

H2b: The number of scientific research personnel in a city is positively correlated with academic cooperation between cities.

In addition to the necessary cultural and technical capabilities for academic cooperation, another important influencing factor is the level of economic development. A good level of economic development can better support the conduct of scientific research and the cooperation between scientific researchers from different cities. A key indicator of whether a city has a good economic situation is its GDP, hence Hypothesis 3 is proposed.

H3: The level of a city's GDP is positively correlated with its academic cooperation.

The urban population, as one of the important characteristics of a city's vitality, has a certain impact on the city's scientific research and academia. Especially under the condition of a good population size and structure, it plays a positive role in promoting the development of scientific and technological capabilities and the conduct of scientific research cooperation, thus Hypothesis 4 is proposed.

H4: The population of a city is positively correlated with its academic cooperation.

One of the important factors affecting scientific cooperation is distance. This study takes the Guangdong-Hong Kong-Macao Greater Bay Area as the research object, so it uses the central points of the 9+2 cities in the Greater Bay Area as the core to calculate their distances from other cities. The closer the distance between cities, the greater the possibility of cooperation, and the higher the possibility of jointly publishing scientific research results. Therefore, Hypothesis 5 is proposed.

H5: The distance between cities is negatively correlated with academic cooperation between cities.

Based on the above analysis, the theoretical framework for the academic cooperation of the Guangdong-Hong Kong-Macao Greater Bay Area with major domestic cities is shown in Figure 8.

4.2 Empirical Analysis of Influencing Factors on Academic Cooperation in the Greater Bay Area

Correlation analysis is used to verify the relationship between academic cooperation outcomes and factors such as culture, scientific research institutions, scientific research

personnel, economy, population, and urban distance. The Pearson correlation analysis is represented by Equation (5).

In the equation, academic cooperation outcomes y_i data is sourced from the WOS, and the degree of each city obtained through the network analysis of the aforementioned Model (2) represents the tightness of the city's cooperation with other cities. The representative factor for culture is the number of universities, denoted as X_1; the number of scientific research institutions is represented by the count of National Key Laboratories, denoted as X_2; the number of scientific research personnel is denoted as X_3, the economic-related GDP is denoted as X_4, the population count is denoted as X_5, and the inter-city distance is denoted as X_6.

Data for X_1 is sourced from the "2018 Educational Statistics," while X_2 and X_3 come from the 2018 Statistical Yearbook of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area. GDP data X_4 and population data X_5 for each city are from the "2018 National Statistical Yearbook." Inter-city distance data X_6 is measured using Baidu Maps, calculating the distances from the centers of the 11 cities in the Greater Bay Area to these centers.

Based on the academic cooperation network analysis mentioned above, this study primarily focuses on 45 Chinese cities with the most publications for empirical analysis to verify the correlation between the data. This includes the 9+2 cities of the Guangdong-Hong Kong-Macao Greater Bay Area as well as major cities in China. SPSS is used to measure the reliability of the data and to complete the standardization of the data through Cronbach's α calculation, which results in 0.829, greater than 0.7, meeting the reliability requirements [31]. For validity measurement, the KMO and Bartlett values are 0.684, with significance sig ($0.000 < 0.001$), basically meeting the validity requirements for the observed objects. SPSS software is used for correlation analysis to verify the effectiveness of the influencing factors. The results are shown in Table 3.

Analysis reveals that H1 has a P-value ($0.00 < 0.01$), and the hypothesis is established, indicating that having more universities and a stronger cultural heritage can promote academic research cooperation between cities in the Guangdong-Hong Kong-Macao Greater Bay Area. H2a has a P-value ($0.014 < 0.05$), and the hypothesis is established, indicating that the establishment and number of scientific research institutions and National Key Laboratories are positively correlated with academic cooperation. H2b has a P-value ($0.000 < 0.05$), and the hypothesis is established, indicating that the more scientific and research personnel there are, the more conducive it is for academic cooperation. H3 has a P-value ($0.000 < 0.01$), and the hypothesis is established, indicating that the more developed the economy of a city, the more it can promote academic cooperation between cities. H4 has a P-value ($0.000 < 0.01$), and the hypothesis is established, indicating that the larger the population scale of a city and the more vibrant it is, the more it can promote academic cooperation between cities. H5 has a P-value ($0.141 > 0.05$), indicating that hypothesis 5 is not established, and it is concluded that the distance between cities is not a factor affecting academic cooperation. The past belief that long distances would hinder academic cooperation is no longer valid in today's society where communication technology is advanced, and researchers from different cities can fully transcend the limitations of geographical distance to carry out academic cooperation.

5. Conclusions and Suggestions

5.1 Research Conclusions

This paper takes the Guangdong-Hong Kong-Macao Greater Bay Area as the subject and constructs a complex network to study its academic cooperation. The research results show:

The academic cooperation network of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area shows a clear structure of core-half-core-periphery and has small-world characteristics, while there is a certain imbalance in the academic development of the Greater Bay Area. Guangzhou, Hong Kong, and Shenzhen are the cores of academic cooperation in the Greater Bay Area, and regions with relatively weaker economy and science and technology, such as Jiangmen, Huizhou, Zhaoqing, etc., have great room for improvement in academic cooperation.

The main academic cooperation partners of the Guangdong-Hong Kong-Macao Greater Bay Area with other regions all show characteristics of more developed economy, stronger science and culture. For example, domestic cooperation partners are cities with many universities and scientific research institutions, with strong scientific research strength and cultural heritage, and developed economy. Internationally, they are countries with more developed economies, stronger scientific research strength, and richer cultural heritage.

The positive correlation factors affecting academic cooperation in the Greater Bay Area include culture, scientific research, economy, and population, etc., and geographical distance is no longer a factor hindering academic cooperation. If a region has more university resources and richer cultural heritage, has more high-level scientific research institutions, has more scientific and research personnel, has stronger economic strength and larger population size, then its academic cooperation performance will be better and its academic cooperation ability will be stronger.

5.2 Research Suggestions

5.2.1 Promote the Joint School Establishment in the Guangdong-Hong Kong-Macao Greater Bay Area

According to the positive correlation between the number of universities a city has and the academic cooperation between cities. At present, there are 180 higher education institutions in the Guangdong-Hong Kong-Macao Greater Bay Area, each with its strengths and weaknesses. Based on this, a Greater Bay Area academic alliance can be established. Promote exchanges and cooperative education between colleges and universities, on the one hand, can increase the number of universities a city has; on the other hand, can strengthen academic cooperation. For example, high-quality university resources in Hong Kong can be introduced to Guangzhou and Shenzhen, and advanced experiences can be brought to other regions of the Greater Bay Area. Through campus construction, strengthen cultural exchanges and social cultural exchanges to promote academic cooperation and development. To build the Guangdong-Hong Kong-Macao Greater Bay Area into a world-class bay area comparable to the New York Bay Area, San Francisco Bay Area, and Tokyo Bay Area, it is necessary to create a cluster of world-class universities.

5.2.2 Strengthen the Construction of Laboratories in the Guangdong-Hong Kong-Macao Greater Bay Area

According to the positive correlation between the number of national key laboratories a city has and the academic cooperation between cities. The construction of key laboratories is conducive to academic cooperation, so a "University Joint Laboratory" in the Guangdong-Hong Kong-Macao Greater Bay Area can be established. With the 26 universities joining the Guangdong-Hong Kong-Macao University Alliance as the backbone, build joint laboratories with school characteristics. Universities in the pilot zone jointly establish research and development centers or joint laboratories to achieve a model of joint enrollment and training, and jointly carry out scientific and technological research and development, further promoting academic cooperation between cities.

5.2.3 Optimize the Research Team Construction in the Guangdong-Hong Kong-Macao Greater Bay Area

Based on the positive correlation between the number of scientific research personnel a city has and the academic cooperation between cities, the quantity of researchers has a positive impact on academic cooperation. Therefore, it is necessary to strengthen the protection and incentive of scientific research talents in the Guangdong-Hong Kong-Macao Greater Bay Area, promote the joint training and cooperative exchange of scientific research talents, promote the rational flow of talent elements, appropriately increase the number of graduate students in the Greater Bay Area, and optimize the structure of graduate students. Fully leverage the policy advantages of the bay area, plan and carry out the docking of talents and industries in the Greater Bay Area, achieve the complementarity and development of industry, academia, and research, and jointly promote the exchange and cooperation of scientific research talents in Guangdong, Hong Kong, and Macao.

5.2.4 Promote Steady Economic Growth in the Guangdong-Hong Kong-Macao Greater Bay Area

Based on the positive correlation between a city's GDP development level and its academic cooperation, economic development can effectively support scientific research work and help promote cooperation in academic research. Taking Hong Kong, Macao, Guangzhou, and Shenzhen, the four central cities, as the core engine for the development of regional academic cooperation, continue to give play to the comparative advantages and exemplary role, and enhance the radiating and driving effect on the academic development of surrounding areas. Support Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, Zhaoqing, and other cities to give full play to their own advantages, develop advantageous industries, promote economic development through industrial development, thereby driving academic cooperation, forming important node cities with functional complementarity and academic competitiveness, and promote academic cooperation through the support of science and technology funds.

5.2.5 Optimize the Talent Structure of the Guangdong-Hong Kong-Macao Greater Bay Area

Based on the positive correlation between a city's population size and its academic cooperation, the scale of talent has a certain impact on academic cooperation. Therefore, strengthen top-level design and optimize the structure of scientific research personnel in the Guangdong-Hong Kong-Macao Greater Bay Area. Fully leverage the policy advantages of the bay area, carry out the docking of resources and talents in the Greater Bay Area, and jointly promote the cooperation and exchange of talents in Guangdong, Hong Kong, and Macao. On the basis of the gradual increase of the population size, improve the cultural level and educational level of the population. Through the interconnection of policies, the mutual support of talent work systems, and the

interpenetration of talent resource markets, promote the free flow of human resources, enhance the vitality of the population in each city, and enhance the comprehensive advantages of the Greater Bay Area in attracting high-end talents from home and abroad. Gradually optimize the population structure of each city in the bay area, especially strengthen the assistance and mobility of Guangzhou, Hong Kong, and Shenzhen to the bay area cities with weaker academic capabilities, and jointly promote academic cooperation in various cities of the Greater Bay Area.

References

1. Organisation for Economic Co-operation and Development. Higher Education and Regions: Engaging Local and Global Perspectives [M]. 2012.

2. Yu Yuxian. Analysis of Cross-Boundary Science and Technology Cooperation Models within Sovereign States: The Case of Science and Technology Cooperation among Guangdong, Hong Kong, and Macao Universities [J]. Science and Technology Management Research, 2010, 30(16): 84-88.

3. Cai Chimeng. The Strategic Significance and Current Challenges of Guangdong-Hong Kong-Macao Greater Bay Area Urban Agglomeration Construction [J]. Guangdong Social Science, 2017(4): 5-14+254.

4. Zhao Xiaobin, Qiang Wei, Huang Weihao. Exploration of Theoretical Framework and Development Strategy for Guangdong-Hong Kong-Macao Greater Bay Area [J]. Progress in Geography, 2019, 37(12): 13-24.

5. Chen Yan, Lin Zhonghao. Grey Correlation Analysis and Coordination Mechanism Innovation of Industrial Collaboration among Cities in Guangdong-Hong Kong-Macao Greater Bay Area [J]. Journal of Guangdong University of Finance & Economics, 2018, 33(4): 89-97.

6. Qin Yanhua, Cao Xiyu. Research on the Collaborative Innovation of Science and Technology among the City Clusters in the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Journal of Central China Normal University (Natural Sciences Edition), 2019, 53(2): 255-262.

7. Xu Xin, Yang Jiaying, Li Dan. Evolution of International Scientific Research Cooperation Network under Science Fund Support: A Bibliometric Analysis Based on WOS Physics Data [J]. Journal of Intelligence, 2019, 38(2): 49-55+48.

8. Wang Zhigang, Qiu Changbo. Analysis of the Evolution of SCI Paper Cooperation Network among Provinces in Mainland China [J]. Information Science, 2019, 37(11): 163-168.

9. Dong Yanbang, Liu Li. Analysis of the Evolution of Institutional Cooperation Network of High-Level Papers in Chinese Universities: Taking the Cooperative Papers in Nature and Science from 1978 to 2017 as Examples [J]. Journal of Intelligence, 2019, 38(11): 138-144+157.

10. Zhu Yunxia. A Model of Scholar Association Based on Co-authorship and Co-citation Relationships and Its Empirical Study [J]. Library Work, 2015, 59(22): 97-104.

11. CALERO C, VAN LEEUWEN T N, TIJSSEN R J, et al. Research cooperation within the bio—pharmaceu- tical industry:Network analyses of co —publications within and between firms [J].Scientometrics,2007,71(1): 87—99.

12. BARBER M J, FISCHER M M, SCHERNGELL T, et al. The community structure of research and devel- opment cooperation in Europe:evidence from a social network perspective [J].Geographical Analysis,2011,43(4):415—432.

13. NEWMAN M E J.The structure and function of com- plex networks[J].Siam Review,2003,45(2):167—256.

14. CHERVEN K. Network graph analysis and visualiza- tion with Gephi[M].packt publishing Ltd,2013.

15. Wang Lin, Zhang Jingjing. Centralization in Complex Networks. Complex Systems and Complexity Science, 2006, 3(1): 13-20.

16. DING Y. Applying weighted pageRank to author cita- tion networks [J]. Journal of the American Society for Information Science and Technology,2011,62 (2):236 — 245.

17. Tian Zhanwei, Sui Chang. An Empirical Analysis of Microblog Information Dissemination Based on Complex Network Theory [J]. Library Information Work, 2012, 56(8): 42-46.

18. FREEMAN L C, BORGATTI S p, WHITE D R. Centrality in valued graphs:a measure of betweenness based on network flow [J].Social Networks,1991,13(2): 141—154.

19. SARAMA KI J, KIVELA M, ONNELA J p, et al.Generalizations of the clustering coefficient to weighted complex networks [J].physical Review E,2007,75 (2): 027—105.

20. Xie Weiwei, Deng Hongbing, Su Pandan. Knowledge Innovation Cooperation Network Research of the Mid-Yangtze River Urban Agglomeration: An Empirical Analysis of High-Level Scientific Research Co-authorship Papers [J]. Science and Technology Progress and Policy, 2019, 36(16): 44-50.

21. Liu Chengliang, Gui Qinchang, Duan Dezhong, Yin Meiyuan. Structural Heterogeneity and Adjacency Mechanism of Global Scientific Research Paper Cooperation Network [J]. Acta Geographica Sinica, 2017, 72(04): 737-752.

22. Liu Liang, Luo Tian, Cao Jiming. Research Method of Scientific Research Cooperation Pattern Based on Multi-scale Complex Network [J]. Science Research Management, 2019, 40(01): 191-198.

23. Tu Jing, Yang Zhonghua, Zhang Zhiqing. The Impact of Knowledge Source Centrality in Scientific Research Cooperation Network on Knowledge Diffusion Efficiency [J]. Theory and Practice of Information, 2017, 40(05): 76-81.

24. WATTS D J, STROGATZ S H. Collective dynamics of 'small-world' networks [J]. Nature, 1998, 393 (6684): 440.

25. DURRANDE, N, GINSBOURGER D, ROUSTANTO, et al. ANOVA kernels and RKHS of zero mean functions for model-based sensitivity analysis [J]. Journal of Multivariate Analysis, 115: 57-67.

26. Wu Jiehua, Zhu Anqing. Analysis and Prediction of Scientific Research Cooperation Relationship Based on Community Structure [J]. Computer Applications and Software, 2016, 33(03): 701-705.

27. Chen Guo, Zhao Yixin. Evolution Model of Domain Knowledge Network Driven by Multiple Factors: Following the Wind, Adhering to the Old, and Innovating [J]. Journal of Information Science, 2020, 39(01): 1-11.

28. FREEMAN C, NELSON R, SILVERBERG G, et al. Technical change and economic theory [M]. G. Dosi "Japan: A New National System of Innovation", Pinter, 1988: 330-348.

29. COOKE P, URANGA M G, ETXEBARRIA G. Regional innovation systems: Institutional and organisational dimensions [J]. Research Policy, 1997, 26(4-5): 475-491.

30. Zhang Jinzhu, Yu Wenqian, Liu Jingyi, Wang Yue. Research on Scientific Research Cooperation Prediction Based on Network Representation Learning [J]. Journal of Information Science, 2018, 37(02): 132-139.

31. BLAND M J, ALTMAN D G. Statistics notes: Cronbach's alpha [J]. BMJ, 1997, 22-572.

Author Biographies

1. School of International Business, Guangdong University of Finance and Economics, Guangzhou, Guangdong 510320; Jiong'en Xiao is a lecturer and senior engineer at Guangdong University of Finance and Economics, and a postdoctoral researcher at the Guangzhou Institute of Software Application Technology, Chinese Academy of Sciences. His research directions include information management and information systems, knowledge engineering and knowledge management, and government information resource management.

2. Guangzhou Saibao Lianrui Information Technology Co., Ltd., Guangzhou, Guangdong 510610; Fan Ni Yang is an engineer at Guangzhou Saibao Lianrui Information Technology Co., Ltd. Her research direction is intelligent algorithms.