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Research on the Collaborative Innovation Network of Chinese Patent Medicine Patents in the Guangdong-Hong Kong-Macao Greater Bay Area Based on SNA Method

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Article

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Research on the Collaborative Innovation Network of Chinese Patent Medicine Patents in the Guangdong-Hong Kong-Macao Greater Bay Area Based on SNA Method

Abstract Collaborative innovation in Chinese patent medicine patents serves as a core pillar for developing the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) into a leading hub of traditional Chinese medicine (TCM). It carries substantial practical significance for addressing the uneven distribution of regional innovation resources and enhancing the core competitiveness of the TCM industry. Drawing on invention patent data for Chinese patent medicines in the GBA from 2016 to 2024 retrieved from the incoPat database, this study constructs a patent cooperation matrix. Employing social network analysis (SNA), it analyzes the structural characteristics and phased evolution patterns of the cooperation network from both actor and spatial dimensions. The quadratic assignment procedure (QAP) is further applied to investigate the association between geographical/technological proximity and patent cooperation. The findings reveal a typical core-periphery structure in the GBA's Chinese patent medicine patent cooperation network, marked by low overall density and pronounced fragmentation. Guangzhou functions as the central spatial hub, while leading universities (including South China Agricultural University and Guangdong Pharmaceutical University) and flagship pharmaceutical enterprises constitute the core nodes of the network. From a phased perspective, the network has expanded notably in scale since 2021: the composition of cooperation actors has shifted from an enterprise-dominated pattern to multi-stakeholder collaboration among industry, academia, research institutions and government; Hong Kong and Macao have gradually integrated into the cooperation system from the periphery; and cross-border and cross-regional collaboration intensity has continued to rise. Both geographical proximity and technological proximity exert a significant positive effect on patent cooperation. This study enriches empirical research on regional innovation in the specific sub-field of Chinese patent medicines, and provides evidence-based support for refining TCM collaborative policies in the GBA.

Keywords: Guangdong-Hong Kong-Macao Greater Bay Area; Chinese patent medicines; Patent cooperation; Social network analysis

1 Introduction

Chinese patent medicine stands as a core vehicle for upholding traditions and driving innovation in TCM, and represents a distinctive sector where China's pharmaceutical industry boasts original technological advantages. In recent years, the rollout of national policy documents—including the *Outline of the Strategic Plan for the Development of Traditional Chinese Medicine* (*2016–2030*) and the *Outline of the Healthy China 2030 Plan*—has been accompanied by growing R&D investment in TCM. Against this backdrop, process upgrading, formulation optimization, and patent output of Chinese patent medicines have all witnessed accelerated growth. Patent cooperation, as a critical pathway to integrate heterogeneous innovation resources, share R&D costs, and accelerate the commercialization of research outcomes, serves as a core indicator of regional collaborative innovation performance. China's 15th Five-Year Plan explicitly calls for improving cross-regional innovation collaboration mechanisms, deepening cross-border industrial cooperation in the GBA, and promoting the revitalization of TCM. These policy priorities provide clear guidance for collaborative patent innovation in the Chinese patent medicine sector.

The GBA is a strategic highland for China's TCM industry development. The nine municipalities in the Pearl River Delta boast a complete industrial chain for Chinese patent medicine manufacturing and concentrated industry-university-research innovation resources, while Hong Kong and Macao feature mature international intellectual property systems and global trade networks, acting as vital bridges for TCM to access global markets. Following the release of the *Plan for Building the GBA into a TCM Highland* (*2020–2025*) in 2020, demand for regional collaborative innovation has grown steadily. Nevertheless, several practical challenges remain: the uneven spatial distribution of innovation resources, insufficient depth of industry-university-research cooperation, institutional barriers to cross-border factor flows, and a low share of high-value core patents. Against this background, there is an urgent need to systematically

clarify the network structure, evolution patterns, and core driving mechanisms of Chinese patent medicine patent cooperation in the region.

Existing research on patent cooperation largely focuses on high-end manufacturing and biomedicine, with limited attention paid to Chinese patent medicine—a niche sector embedded with traditional knowledge attributes. At the regional level, relevant studies concentrate on East China and the Yangtze River Delta. Research on the GBA mostly remains at the level of aggregate patent statistics and innovation efficiency measurement, failing to deconstruct the structural characteristics and influencing factors of the cooperation network in depth. This gap makes it difficult to provide solid empirical support for the refined formulation of regional collaboration policies[1-8].

To address this gap, this study draws on invention patent data of Chinese patent medicines in the GBA from 2016 to 2024 from the incoPat database. It adopts social network analysis to portray the characteristics and evolution patterns of the cooperation network from multiple dimensions, and uses QAP regression to test the impacts of geographical and technological proximity on patent cooperation. The findings will enrich empirical research on TCM innovation management, and provide data references for the GBA to improve the collaborative innovation mechanism for Chinese patent medicines and optimize cross-regional cooperation policies.

2 Literature Review

2.1 Research Progress in Patent Cooperation

Patent cooperation refers to activities carried out by diverse innovation actors—including enterprises, universities, and research institutions—through joint patent applications and technology sharing. Its core lies in patent-based connections among actors, rather than generalized industrial collaboration[9] [10]. Social network analysis is inherently aligned with patent cooperation research: interconnections among patent applicants form a patent cooperation network[10] , and joint patent applications effectively capture the properties and features of social networks[11]. Existing literature examines the characteristics of patent cooperation networks from regional, industrial, and university-enterprise perspectives, and two main consensuses have been reached.

First, geographical proximity and technological proximity are the primary factors shaping patent cooperation [8], [14], [15] . Geographical proximity reduces inter-regional communication costs and barriers to knowledge spillovers, and the transmission of complex knowledge is particularly dependent on it [1] , while technological proximity effectively improves the efficiency of knowledge absorption and transformation. However, some studies find no significant positive effect of geographical proximity on the quality of patent cooperation[12]. Second, university-enterprise collaboration has become the dominant form of patent cooperation, and its value has been widely verified[12], [16-18]. The knowledge heterogeneity of universities compensates for the shortcomings of enterprise R&D [16] . In recent years, the depth and breadth of university-enterprise cooperation have increased year by year[17] , further driving the upgrading of patent innovation quality[12]. Meanwhile, the traditional model—where universities lead scientific and technological innovation and enterprises take charge of commercialization—is gradually shifting to a model of joint university-enterprise development[18]. However, existing studies on patent cooperation in industry-university-research settings mostly focus on single actor pairs, and few simultaneously incorporate all four types of innovation actors: enterprises, universities, research institutions, and government agencies.

2.2 Research on Chinese Patent Medicine Patent Cooperation and the GBA

Research on Chinese patent medicine patents has evolved from nationwide macro analysis to refined regional studies.

At the national level, existing studies focus on the interactions among cooperation actors and the overall innovation characteristics of TCM patents. For instance, Yang et al.[19] systematically sorted out the regional development patterns and actor distribution of TCM compound formula patents in China; Li et al.[20]analyzed the network structure and actor connection patterns of collaborative innovation in China's TCM sector; and He et al. [21] revealed the evolution of industry-university-research collaborative innovation in the TCM industry. Zhen[22] pointed out a widespread issue with Chinese patent medicine patents in China: despite a large total number of applications, their overall value remains low. The author argued that cultivating high-value patents is

highly dependent on a collaborative industry-university-research innovation system and systematic patent layout.

At the regional level, research mainly focuses on East China and the Yangtze River Delta urban agglomeration. For example, Tang et al. [23] depicted the overall structure and actor characteristics of the medical industry-university-research cooperation network in East China based on patent cooperation data; Xu et al. [24] analyzed the development patterns and spatial distribution of the TCM industry innovation network in the Yangtze River Delta from a spatiotemporal evolution perspective. These studies provide reference paradigms for regional research on Chinese patent medicine patent cooperation.

Existing studies on TCM innovation in the GBA mainly focus on two dimensions: patent layout and innovation efficiency. Regarding patent layout, Zhi [25] reviewed the overall application trend of TCM patents in the GBA, finding that industry actors have strong motivation to apply for patents, but generally face long grant cycles for invention patents and low overall patent quality. Chen et al.[26] further analyzed the current layout of TCM patents in the GBA, pointing out the uneven distribution of regional innovation resources: core resources are highly concentrated in mainland cities, and there is insufficient synergy between university R&D and industrial application by enterprises. Regarding innovation efficiency, Pan et al.[27] and Huang et al.[28] measured the efficiency of TCM scientific and technological innovation and the construction efficiency of the internationalization highland in the GBA, respectively. Both studies concluded that insufficient innovation linkages among cities and ineffective integration of patented technology resources are core bottlenecks restricting the high-quality development of regional TCM.

To sum up, existing research presents three major features. First, the academic community has widely verified the role of patent cooperation in improving innovation efficiency, forming a research paradigm that uses social network analysis to map cooperation network characteristics and examines core driving factors from the perspective of proximity. Second, it is established that China's Chinese patent medicine innovation has shifted from scale expansion to quality improvement, and that industry-

university-research collaboration and the radiation effect of core actors play a key role in addressing patent pain points such as low-level homogenization. Third, the GBA combines mainland industrial resources with the international advantages of Hong Kong and Macao for TCM development. However, the uneven spatial distribution of innovation resources and insufficient cross-border and cross-actor linkages mean that deepening cross-regional collaborative innovation is critical for building a high-quality TCM highland.

Nevertheless, research gaps remain. First, there is a lack of fine-grained sub-sector research. Most existing GBA-focused studies cover the entire industry or TCM as a whole, without narrowing down to Chinese patent medicines or providing an accurate depiction of their patent cooperation network characteristics. Second, the research perspective needs to be deepened. Most existing findings focus on status description and efficiency measurement, and few systematically analyze the overall structure, core actors, and evolution patterns of Chinese patent medicine patent cooperation using social network analysis. Third, the driving mechanism remains under-explored. No existing study has combined proximity theory to empirically test the impacts of multi-dimensional factors such as geography and technology on Chinese patent medicine patent cooperation in the GBA, making it difficult to provide precise empirical support for cross-regional collaboration policy-making.

Accordingly, this study takes the Chinese patent medicine patent cooperation network in the GBA as its research object. Using patent data and social network analysis, it incorporates universities, enterprises, research institutions, and government agencies into the analytical framework, with the aim of supplementing research on innovation and cooperation in the TCM field, strengthening Chinese patent medicine patent cooperation capacity, and promoting innovation-driven development in the GBA.

2.3 Research Hypotheses

Existing studies have identified geographical proximity and technological proximity as core factors shaping patent cooperation networks (Yu et al.[14] , Zhong et al.[8], Xi et al.[15] , Zhang et al.[1]).

Geographical proximity refers to the degree of spatial adjacency between two

cooperating actors[14]. Tobler's First Law of Geography states that spatially closer entities are more strongly correlated. The theory of spatial dependence also holds that the similarity of geographic phenomena is closely related to their spatial distance, reflecting real-world spatial interactions such as inter-regional factor flows, knowledge diffusion, and spillovers[29]. Patent cooperation in the GBA relies heavily on inter-city transportation connectivity. Since Guangzhou, Shenzhen, and Foshan are major hubs for Chinese patent medicine R&D, joint patent development between applicants is more likely to occur within the same city or between adjacent cities. It can therefore be inferred that geographical proximity significantly promotes Chinese patent medicine patent cooperation in the GBA. Accordingly, the first hypothesis is proposed:

H1: Geographical proximity has a significant positive impact on Chinese patent medicine patent cooperation in the GBA.

Technological proximity refers to the similarity in technological experience and knowledge base between cooperating parties[30] . Jaffe proposed a method for measuring technological relatedness, on the basis of which Petruzzelli[31] constructed measurement approaches using patent IPC classification information to gauge the technological proximity between two actors. In Chinese patent medicine research, IPC classification codes directly reflect the research field of a patent. They can be used to identify the degree of IPC overlap between different patents and infer the likelihood of patent cooperation. On this basis, the second hypothesis is proposed:

H2: Technological proximity has a significant positive impact on Chinese patent medicine patent cooperation in the GBA.

3 Methods

3.1 Methods

This study conducts empirical analysis using social network analysis (SNA) and the quadratic assignment procedure (QAP). SNA constructs an undirected network with innovation actors as nodes and patent cooperation relationships as edges. It is used to examine the overall structure, node characteristics, and spatial distribution patterns of Chinese patent medicine patent cooperation in the GBA. Indicators such as network density, network centrality, and cohesive subgroups are applied to analyze the

connectivity of the cooperation network, the features of core actors, and cooperation patterns among actors. QAP regression is used to test the influencing factors of patent cooperation relationships. It does not require the assumption of variable independence, making it suitable for analyzing interconnected patent cooperation networks and testing the effects of geographical and technological proximity on cooperation.

3.2 Data Sources

The incoPat global patent search platform, a professional patent intelligence analysis system, is used for patent data retrieval in this study. On February 22, 2016, the State Council issued the *Outline of the Strategic Plan for the Development of Traditional Chinese Medicine (2016–2030)*, marking the elevation of TCM development to a national strategic priority. Considering the 18-month publication lag of invention patents, and to ensure sufficient sample size, the data collection period is set from February 22, 2016 to December 31, 2024, divided into two phases: Phase 1 (2016–2020) and Phase 2 (2021–2024). The issuance of the *Outline* in 2016 and the *Plan for Building the GBA into a TCM Highland (2020–2025)* in 2020 are two key milestones. These two phases coincide with China's 13th and 14th Five-Year Plan periods. Analyzing the characteristics and development patterns of Chinese patent medicine patent cooperation in the GBA along this timeline can provide insights for patent layout in the region during the 15th Five-Year Plan period.

The retrieval criteria for Chinese patent medicine patents are as follows:

Following the research of Cao [32] , the search covers 42 dosage forms of Chinese patent medicines included in the *Chinese Pharmacopoeia* and *New National Chinese Patent Medicines*, as well as 125 medicinal materials ranked in the top 25 by usage frequency across botanical, zoological, mineral, chemical, and other categories.

Invention patents for Chinese patent medicines are retrieved using a combined strategy of "application date + title and abstract", with the time range limited to February 22, 2016 to December 31, 2024.

The geographical scope covers 11 cities in the GBA: Guangzhou, Shenzhen, Foshan, Zhuhai, Dongguan, Jiangmen, Zhongshan, Huizhou, Zhaoqing, Hong Kong, and Macao.

Applicant types are limited to four categories: enterprises, universities, research institutions, and government agencies; individual applicants and other types are excluded.

IPC classification codes are restricted to A61K36/00 (pharmaceutical preparations containing algae, lichens, fungi or plant material) and A61K35/00 (pharmaceutical preparations containing substances of undetermined composition or their reaction products).

The initial search yielded 4,070 patent records. The following ineligible samples were excluded sequentially: patents co-applied by a single enterprise/university/research institution/government agency with an individual; cross-regional patents involving only one GBA city and a city outside Guangdong Province; independent patents with a single applicant; and duplicate patent application records. Finally, 2,593 valid patent records were obtained, including 170 cooperative patents. After deduplication of patent applicants, 213 innovation actors were included as research samples.

Ucinet 6.212 software is used to analyze network node characteristics, overall network structure, and cohesive subgroups. By constructing a social network of Chinese patent medicine patent cooperation in the GBA, this study reveals the features of the cooperation network. Meanwhile, the ForceAtlas2 layout and Modularity Class function in Gephi 0.10.1 are adopted to generate visualized social network maps.

As shown in Table A1, this study mainly calculates the centrality, network density, cohesive subgroups, and core-periphery structure of Chinese patent medicine cooperation actors. After deduplication, 2,593 cooperation actors are identified. The study covers 18 regions centered on the GBA, including nine Pearl River Delta cities, the Hong Kong and Macao Special Administrative Regions, other cooperative cities within Guangdong Province, and a small number of cities classified as “non-Guangdong”. Four types of cooperation actors are included: universities, enterprises, research institutions, and government agencies.

Centrality refers to the extent to which a node is positioned at the center of a network. Centrality analysis captures the importance of a node and reflects the influence

of an individual or organization in a social network[34]. This study employs relative degree centrality, relative betweenness centrality, and relative closeness centrality for analysis. Degree centrality, based on node degree, measures the extent to which a node is directly connected to other nodes[35]. A higher centrality value indicates a more important position or greater power in the network structure[36]. Closeness centrality measures the average shortest path length from a given node to all other nodes in the network [33]. Betweenness centrality refers to the extent to which a node lies on the shortest paths between other pairs of nodes[33].

Cohesive subgroups are analyzed from four perspectives: reciprocity of edges, frequency of edges among subgroup members, proximity or reachability among subgroup members, and the density of internal edges relative to external edges. Among them, *N*-clique is a reachability-based cohesive subgroup, defined as a maximal subgraph in an undirected graph where the distance between any two nodes within the subgraph does not exceed *N*[37] [38]. *K*-plex and *K*-core are degree-based cohesive subgroups, derived by constraining the number of neighbors for each member in the subgroup. A *K*-plex is a maximal subgraph of size n where each node has a degree of at least $n-k$ within the subgraph[39] [40]. A *K*-core is a maximal connected induced subgraph in an undirected graph where all nodes have a minimum degree of at least *K*[41]. A component is a cohesive subgroup defined by internal versus external edges: if a graph can be divided into several parts, members within each part are connected, and there are no edges between different parts.

Cohesive subgroup analysis can only divide a network into multiple subgroups but cannot identify the hierarchical structure of nodes within subgroups. Therefore, this study further introduces the discrete core-periphery model to examine the vertical structure of the network. Proposed by Borgatti and Everett[42], the discrete core-periphery model assumes the existence of core actors and peripheral actors in a network, satisfying three conditions: first, all core actors are connected to each other; second, all peripheral actors are not connected to each other; third, connections between core and peripheral actors are unrestricted.

The study uses the built-in ForceAtlas2 algorithm in Gephi to generate visualized

network maps. Based on the Barnes-Hut mechanical model, this algorithm performs iterative calculations by simulating attractive and repulsive forces between nodes to construct the topology of the cooperation network. As shown in Table A2, the modularity indicator is calculated using the community detection algorithm proposed by Blondel et al. [45] , which identifies network subgroups based on the modularity Q value. The scale of subgroup division follows the multi-scale modularity theory of Lambiotte et al., which is used to stratify cohesive subgroups in the GBA's Chinese patent medicine patent cooperation network.

4 Results

4.1 Overall Network Structure

Centrality analysis, network density analysis and cohesive subgroup analysis are performed on the applicants, applicant cities and applicant types extracted from the 2,593 patent records using Ucinet.

4.1.1 Overall Network of Patent Applicants

The cooperation network of Chinese patent medicine patent applicants in the GBA is characterized by tight local clusters but weak overall connectivity. As shown in Table A3 and Table A4, the network comprises 1,195 nodes and only 142 cooperative edges, with a network density as low as 0.0001 and an average centrality close to zero. The vast majority of applicants are isolated nodes, indicating that independent R&D remains the dominant patent application model.

The network exhibits distinct core-periphery stratification, with only a small number of highly connected core actors. As illustrated in Figure A1, a few tightly-knit industry-university-research cooperation subgroups have emerged within the network. As listed in Table A5, South China Agricultural University is the core hub of the network with 12 connection edges. Guangdong Pharmaceutical University, South China University of Technology, and Shenzhen Osa Pharmaceutical form the second tier with 5 connection edges each, while most other actors have fewer than 3 cooperative edges. Overall, core subgroups are highly concentrated, but there is a lack of effective linkages between subgroups, resulting in prominent fragmentation.

4.1.2 Overall Network by City

The statistical scope of applicant cities covers nine Pearl River Delta cities

(Guangzhou, Jiangmen, Shenzhen, Dongguan, Zhongshan, Foshan, Huizhou, Zhuhai, Zhaoqing) and the two special administrative regions of Hong Kong and Macao. To examine the potential impact of extra-regional cooperation, six non-GBA cities in Guangdong Province (Yunfu, Yangjiang, Meizhou, Heyuan, Chaozhou, Qingyuan) are included in the calculation. Cross-regional patent cooperation involving two or more Guangdong cities and cities outside the province are uniformly classified as "non-Guangdong". In total, 18 different applicant cities are covered, including core cooperation regions and cross-regional partners.

Inter-city Chinese patent medicine patent cooperation in the GBA has formed a stable single-center radiation pattern. As shown in Table A6, the overall network includes 18 cities and only 30 cooperative edges, with a network density of 0.0980, indicating early-stage cross-regional linkage. The centrality results in Table A7 show that Guangzhou ranks first in the GBA in terms of degree centrality, closeness centrality, and betweenness centrality, serving as the core hub of regional cooperation. Shenzhen, Foshan, Zhongshan, and Hong Kong form a secondary cooperation circle, while the remaining cities lie at the periphery of the network. The cluster analysis diagram (Figure A2) presents a clear single-peak pattern, confirming the existence of a core-periphery spatial structure[8].

Guangzhou and Jiangmen are jointly identified as the core region. As shown in Table A8 and Table A9, the goodness of fit of the core-periphery model reaches 0.827. The internal cooperation density of the core region is 5.000, far higher than 0.046 for peripheral regions, indicating tight and stable cooperation within the core. The results in Figure A3 and Table A10 show that Guangzhou is connected to 16 peripheral cities, while Jiangmen, despite strong tie weights, only maintains close cooperation with Guangzhou and has no direct edges with other peripheral cities. This finding is consistent with the discrete core-periphery model proposed by Borgatti and Everett[42], where the algorithm prioritizes maximizing connection density within the core. Since the cooperation intensity between Jiangmen and Guangzhou is higher than the average cooperation intensity among peripheral cities, including Jiangmen in the core region significantly improves the overall model fit. In summary, Chinese patent medicine

patent cooperation in the GBA exhibits an obvious single-center radiation feature. Some neighboring cities only establish direct cooperation with the core city, and horizontal linkages between secondary cities have not yet formed.

4.1.3 Overall Network by Applicant Type

After excluding individual applicants, four types of actors remain: enterprises, universities, research institutions, and government agencies.

In terms of applicant type, the participation of the four categories of actors is gradually balancing. As shown in Table A11, enterprises account for 34% of cooperation, making them the most active cooperation actors; universities and research institutions account for 29% and 24% respectively, serving as important pillars of industry-university-research cooperation; government agencies account for a relatively low share of only 13%. In addition, the network centralization is 31.48%, indicating a certain central tendency in the network, dominated by a small number of core actors such as leading enterprises and top universities.

As shown in Figure A4, the cooperation model presents a clear industry-university-research-led feature, with high frequency of enterprise-university and enterprise-research institution cooperation. Traditional university-enterprise cooperation remains the main path of industry-university-research collaboration. There is still considerable room for improvement in linkages between government agencies and other actors.

Overall, the overall network is characterized by large scale but low density, prominent core subgroups but overall fragmentation. At the applicant level, a small number of core nodes such as South China Agricultural University, Guangdong Pharmaceutical University, and Guangzhou Institute of Respiratory Health each form small-scale cooperation subgroups, but there is insufficient linkage between actors and many isolated nodes. At the city level, the network presents a significant core-periphery structure: although Guangzhou and Jiangmen are both core cities, Guangzhou is the absolute core hub, while Shenzhen, Foshan, Zhongshan, and Hong Kong form a secondary cooperation circle, and other cities are at the edge of the cooperation network. At the applicant type level, the participation of enterprises, universities, research

institutions, and government agencies is gradually balancing, but enterprises still dominate, and university-enterprise cooperation is the main form of cooperation.

4.2 Sub-network Analysis by Phase

Patents with application numbers from CN20161 to CN20201 are classified into the 2016–2020 phase, yielding 767 patent records. Patents from CN20211 to CN20241 are classified into the 2021–2024 phase (8 patents with CN20251 numbers published in 2024 are also included), yielding 1,826 records.

4.2.1 Sub-network of Patent Applicants by Phase

The two phases show evolutionary characteristics of expanding network scale and diversifying actors. As shown in Table A12, the cooperation scale was relatively small in 2016–2020, with only 71 cooperation nodes and 40 cooperation edges and a network density of 0.0002. In 2021–2024, the number of cooperation actors increased significantly to 175 nodes and 109 edges, representing growth of 146% and 172% respectively. The network density decreased to 0.0001, with widespread participation of universities and research institutions, but the fragmentation problem remains unresolved.

From the change in centrality, the average number of connections per node decreases, while the connection strength of core nodes increases. As shown in Table A13, degree centrality and betweenness centrality both decline significantly overall, with betweenness centrality nearly zero and no obvious change. This reflects that the expansion of nodes outpaces the growth of cooperative edges, leading to a decline in average connections. However, the maximum value of degree centrality rises from 0.72 to 0.96, indicating an increase in the number of connections for a small number of core nodes and further improvement in network centralization.

Overall, the Chinese patent medicine patent cooperation network in the GBA has gradually evolved from a small-scale, enterprise-led model with dispersed universities and research institutions in the first phase to a multi-stakeholder industry-university-research-government collaboration pattern in the second phase, with a large number of universities and research institutions participating. As shown in Table A14 and Table A15, connections between nodes have strengthened, with up to 9 cooperative applicants.

Compared with the first phase, the second phase sees more applicants with 2 or more cooperative edges, and the number of actors participating in the Chinese patent medicine patent cooperation network has increased. However, problems such as declining network density, loose nodes, and low cooperation activity still need to be optimized, and the network maintains its core-periphery characteristics.

4.2.2 Sub-network by Applicant city

The connectivity and coverage of the city cooperation network have improved significantly, and cross-border collaboration has deepened further. As shown in Table A16, the network density was 0.0381 with only 8 cooperation edges in 2016–2020; by 2021–2024, the network density rose to 0.0956 and the number of edges increased to 26. In terms of centrality, coverage expanded from 15 to 17 cities. As shown in Table A17, the 2016–2020 network was overall disconnected, with no cooperative edges in multiple regions such as Huizhou, Zhuhai, and Macao. Only Guangzhou and Foshan served as dual cores, acting as important bridges connecting applicant cities. In 2021–2024, cooperative cities expanded to include non-GBA cities in Guangdong such as Heyuan, Chaozhou, and Qingyuan. Guangzhou's core position in the GBA is further strengthened; Shenzhen, Foshan, Hong Kong, Zhongshan, and Zhaoqing, as the second tier, are gradually integrated into the cooperation network; while Zhuhai, Dongguan, Jiangmen, and Huizhou have low centrality indicators and remain at the edge of the network.

As shown in Figure A5 and Figure A6, both phases present a single-peak pattern, indicating that the core-periphery characteristic of the GBA's Chinese patent medicine patent cooperation network remains unchanged, but the network structure has shifted from high concentration to moderate dispersion. The dual-core cities have changed, and regional balance has improved. The overall network results point out that both Guangzhou and Jiangmen are at the core level, but Jiangmen's cooperation intensity in the single-phase network does not reach the threshold of a core node. Therefore, as shown in Table A18 , the dual core of Guangzhou-Foshan in 2016–2020 has shifted to the dual core of Guangzhou-Shenzhen in 2021–2024, with the goodness of fit dropping from 0.903 to 0.830.

The overall data show that the pattern of the Chinese patent medicine patent cooperation network in the GBA has changed significantly: as shown in Figure A7 and Table A19, from the early stage with sparse inter-city cooperation, mainly small circles with Guangzhou and Foshan as the core and some small subgroups, it has gradually evolved into the situation shown in Figure A8 and Table A20, with Guangzhou as an important core hub, linking neighboring cities such as Shenzhen, Foshan, Zhongshan and Jiangmen to cooperate with each other. Meanwhile, with the further expansion of subgroup scale, declining fitness, and the transformation of Hong Kong and Macao from peripheral cities to in-depth participation, it indicates that the breadth, depth and collaboration efficiency of Chinese patent medicine patent cooperation have been further improved.

4.2.3 Applicant Type Sub-Network Analysis

Since there are only four types of applicant entities (enterprises, universities, research institutions and government agencies), the number of research entities is limited. Therefore, only network density and centrality analysis are conducted, and further research through cohesive subgroups is not feasible. The balance of the entity type cooperation network has improved. As shown in Table A21 and Table A22 , the network density was 0.5833 in 2016–2020, with universities and research institutions as the core connection nodes. From 2021 to 2024, the network density reached 1, and the centrality data of all entities completely converged, forming a balanced participation of enterprises, universities, research institutions and government agencies in industry-university-research-government collaboration.

In 2016–2020, university-enterprise collaboration was the dominant pathway; government agencies had sparse edges with universities and no established collaboration with enterprises (Figure A9). In 2021–2024, government agencies built connections with all three other actor types, and the four-party collaboration network became increasingly integrated (Figure A10).

Overall, driven by the GBA development plan and supporting policies, notable changes have taken place across applicant, city and type dimensions between the two phases. At the applicant level, the network has evolved from small-scale enterprise-led

collaboration to large-scale multi-actor coordination, with significant expansion in both overall network and subgroup size and a doubling in the number of actual collaboration edges. At the city level, Guangzhou has further consolidated its position as the core hub. The core structure has gradually shifted from a Guangzhou-Foshan dual core to a Guangzhou-Shenzhen dual core, driving cities such as Shenzhen, Foshan and Zhongshan to form a stable core tier. Meanwhile, Hong Kong and Macao have moved from peripheral positions to deeper integration, effectively improving the efficiency of cross-border collaboration. Although the core-periphery structure remains unchanged, the breadth and depth of patent cooperation across cities have increased markedly. At the actor type level, the collaboration model has evolved from an early enterprise-dominated pattern with independent research by universities and research institutions, to a four-party multi-stakeholder collaborative model with balanced participation from enterprises, universities, research institutions and government agencies. The Chinese patent medicine patent cooperation network in the GBA is becoming increasingly mature.

4.3 QAP Regression Analysis

QAP correlation and regression analyses are conducted to verify the impacts of geographical proximity and technological proximity on Chinese patent medicine patent cooperation in the GBA, test the research hypotheses proposed above, and reveal the core driving factors of the collaboration network.

4.3.1 QAP Correlation Analysis: Collaboration Edges and Proximity

QAP correlation analysis is used to examine the relationships between applicant collaboration edges and the two dimensions of proximity: geographical and technological.

As shown in Table A23, geographical proximity is significantly and positively correlated with applicant collaboration. The QAP correlation coefficient between applicant collaboration and city-level collaboration is 0.07, significant at the 0.1% level, indicating that applicants in closer geographical proximity are more likely to collaborate. Technological proximity is also significantly and positively correlated with collaboration, with a QAP correlation coefficient of 0.02, significant at the 1% level.

This suggests that technological proximity exerts a clear facilitating effect on collaboration: the higher the technological relevance between institutions, the stronger their inclination to cooperate. In summary, both geographical and technological proximity exert positive effects on applicant collaboration.

4.3.2 QAP Regression Analysis

(1) Variable Specification and Model Construction

To identify the driving factors of the Chinese patent medicine patent cooperation network in the GBA, this study selects geographical proximity and technological proximity as the two core independent variables, and constructs a QAP regression model with the existence of patent cooperation between institutions as the dependent variable.

Dependent variable: Applicant collaboration matrix *Y*. A value of 1 is assigned if there is a record of joint patent application between two applicants; otherwise 0. After deduplication, a total of 213 applicants are included in the sample.

Independent variables:

Geographical proximity (X_1): Indicates whether two institutions are located in the same city (same city = 1, different cities = 0), used to test the impact of spatial distance on collaboration.

Technological proximity (X_2): A 0–1 co-occurrence matrix constructed based on IPC classification codes, with the degree of technological overlap between institutions calculated by cosine similarity, ranging from 0 to 1. A higher value indicates greater technological overlap and stronger technological proximity between two applicants, used to test the impact of technological similarity on collaboration.

Random disturbance term: ε represents the random disturbance term of the model, capturing the impacts of other unconsidered potential factors on patent cooperation.

The regression model is specified in Equation (1)：

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (1)$$

Where β_0 is the constant term; β_1 and β_2 are the regression coefficients for geographical proximity and technological proximity, respectively.

(2) Analysis of Regression Results

As shown in Table A24, the QAP multiple regression model with applicant collaboration as the dependent variable is statistically significant overall. However, the adjusted R^2 is small: geographical and technological proximity together explain only 0.5% of the variance in the applicant collaboration network, indicating that applicant collaboration is also influenced by other key factors not included in the model. Nevertheless, given the high individual heterogeneity and strong noise inherent in social network edges a low R^2 still retains valid explanatory power.

The standardized coefficient of city proximity is 0.068792, significant at the 0.1% level. This indicates that geographical proximity significantly promotes applicant collaboration: applicants in closer geographical distance are more likely to establish collaborative edges, and geographical proximity exerts the stronger effect of the two proximity dimensions. The standardized coefficient of technological proximity is 0.022189, significant at the 1% level, indicating that technological proximity also has a significant impact on applicant collaboration. The higher the technological relevance between institutions, the stronger their inclination to cooperate.

To clearly illustrate the characteristics of core collaboration subgroups, only the largest node in each subgroup (or representative nodes for subgroups of similar size) are included in the legend; all other small nodes are grouped under “Other applicants”. As shown in Figure A11, South China Agricultural University serves as the core hub of the entire network, connecting diverse actors including enterprises and research institutions, and forming multiple core collaboration subgroups with Guangdong Pharmaceutical University, Guangzhou Institute of Respiratory Health and other institutions.

As shown in Figure A12, modularity classification is performed for the 18 cities. In most collaboration subgroups, Guangzhou appears as the largest node, indicating its role as a key connecting node. Although cities such as Shenzhen, Foshan, Zhuhai and Jiangmen rank second only to Guangzhou in total collaboration nodes and lie in the core tier, they form fewer large-scale collaboration subgroups. Collaboration in other peripheral cities is relatively single-track, tending toward intra-regional cooperation.

Overall, the regression results and overall network data confirm that geographical proximity positively influences Chinese patent medicine patent cooperation among applicants in the GBA. Apart from Guangzhou's geographical advantages as the provincial capital and its abundant urban resources, the core tier of Shenzhen, Foshan and Zhongshan also has relatively more collaboration, but overall still relies heavily on local or neighbouring cooperation, leaving considerable room for improvement in cross-regional collaboration.

As shown in Figure A13 and Table A25, Gephi modularity analysis is applied to cluster 528 IPC categories based on technological similarity in collaboration, yielding 6 technology clusters. According to the characteristics of core IPCs in each cluster, they can be broadly categorised as: medicine-food homology type, plant-based type, cosmetics type, anti-inflammatory and anti-infective type, anti-tumour and antibacterial type, and natural product type. It can be inferred that Chinese patent medicines in the GBA mainly use natural medicines such as plants and fungi as raw materials, covering diverse fields including dietetic health care, anti-inflammation and analgesia, antibacterial and antiviral effects, anti-tumour therapy, and anti-ageing. The three most frequently occurring IPCs in applicant patent cooperation are selected as typical representatives for each category; after removing duplicates, 20 core IPCs are identified. Among them, A61P denotes specific therapeutic activity of chemical compounds and medicinal preparations, while A61K refers to preparations for medical, dental or toilet purposes. Although Chinese patent medicines are based on A61K pharmaceutical preparations, A61P is the most frequently occurring technology type in Chinese patent medicine patents. Patent innovation in Chinese patent medicines is more clearly oriented toward therapeutic uses and indications, reflecting the medicinal value of the products.

In summary, the Chinese patent medicine patent cooperation network in the GBA has initially taken shape, with Guangzhou as the regional core and South China Agricultural University as the key actor hub, covering diverse health fields with natural raw materials. However, there remain problems of imbalanced actor structure and insufficient cross-regional coordination. It is necessary to further break down

institutional and regional barriers, and strengthen multi-party collaboration among industry, academia, research institutions and government.

The standardized coefficient of the city collaboration matrix is 0.068792 (p<0.001). Both correlation and regression analyses show a significant positive relationship, thus Hypothesis 1 (geographical proximity has a significant impact on Chinese patent medicine patent cooperation in the GBA) is supported. The standardized coefficient of the technological collaboration matrix is 0.022165 (p=0.002<0.01). Both correlation and regression analyses show a significant positive relationship, thus Hypothesis 2 (technological proximity has a significant impact on Chinese patent medicine patent cooperation in the GBA) is also supported. Therefore, both research hypotheses proposed in this study are verified. The results indicate that Chinese patent medicine patent cooperation in the GBA is mainly driven by geographical proximity and technological proximity, and innovation actors tend to cooperate with counterparts in the same city and with high technological similarity.

5 Discussion

5.1 Expanding Network Scale with Fragmented Isolated Nodes

From 2016 to 2024, the scale of the Chinese patent medicine patent cooperation network in the GBA has continued to expand. Total patent applications grew from 767 to 1,826, with a marked increase in both the number of collaborating actors and the number of collaboration edges. Driven by a series of supporting policies, awareness of innovative collaboration in the Chinese patent medicine sector has risen, with diverse actors participating in cooperation.

In terms of overall network structure, the network density is extremely low and the number of isolated nodes is large. Among the 2,593 patent records, only 170 involve collaboration. The vast majority of applicants still file patents independently, without forming collaborative edges with other applicants. This results in weak connectivity and insufficient linkage between nodes, leading to scattered distribution of network nodes and the formation of mostly small collaboration subgroups. This indicates that independent R&D remains the dominant innovation model for Chinese patent medicines in the GBA; although collaborative cooperation has deepened, it has not yet

become the mainstream mode of innovation.

Regarding the distribution of core nodes, although applicants such as South China Agricultural University, Guangdong Pharmaceutical University and Guangzhou Institute of Respiratory Health serve as core hubs, their radiation effect is limited. A large number of small and medium-sized enterprises, primary medical institutions and local research institutes have not been effectively integrated into collaboration and remain at the periphery of the network. This reflects that innovation resources in the Chinese patent medicine sector are relatively concentrated in large cities and leading enterprises, while small and medium-sized applicants have narrow channels for participation. The overall collaboration network is characterised by tight local clusters and loose overall connectivity.

At the collaboration subgroup level, most are small partnerships of 3–5 actors. Changes in node collaboration between the two phases show that although collaboration subgroups have basically formed an industry-university-research pattern, they lack long-term stable cross-type and cross-regional cooperation. This suggests that current collaboration is dominated by small-scale short-term partnerships, and a systematic, large-scale and long-term multi-stakeholder collaboration mechanism among industry, academia, research institutions and government has not yet been formed, which further restricts the innovation efficiency and knowledge spillover efficiency of subsequent Chinese patent medicine patents.

Three main factors account for the aforementioned fragmentation characteristics: first, most innovation actors focus on independent R&D and application, with insufficient awareness of patent cooperation and narrow cooperation channels; second, the radiation scope of core actors is limited, and small and medium-sized enterprises and grassroots institutions remain at the periphery of the collaboration network; third, most patent cooperations are short-term, lacking long-term stable coordination mechanisms, resulting in weak connectivity and loose nodes in the network.

5.2 Unbalanced Regional Development with Limited Core City Radiation and a Distinct Core-Periphery Spatial Pattern

Both the overall city-level network and the phase-based sub-networks show that

Chinese patent medicine patent cooperation in the GBA presents a significant core-periphery structure. According to the core-periphery model estimation, Guangzhou and Jiangmen together form the network core. Guangzhou ranks first in degree centrality, closeness centrality and betweenness centrality; Shenzhen, Foshan, Zhongshan and Hong Kong form a secondary tier; and cities such as Dongguan, Zhaoqing, Huizhou and Macao lie at the periphery. As shown in Figure A12, Guangzhou accounts for 51.64% of total patent applications, serving as the absolute core city of regional collaboration. As the second largest city, Shenzhen accounts for only 10.33% of patent applications, revealing a marked gap in regional resources. Evidently, regional collaboration is highly unbalanced, with patent cooperation highly concentrated in core cities and showing clear spatial agglomeration. Although Hong Kong and Macao have gradually entered the collaboration network, cross-border collaboration is limited in quantity and depth. Macao has not yet established collaborative edges with the core hub Guangzhou, and remains overall at the periphery of the collaboration network, failing to give full play to synergistic innovation linkages with inland areas.

This indicates that innovation factors are highly concentrated in core cities, while peripheral cities have insufficient capacity to absorb innovation resources, and the inter-city collaboration mechanism is imperfect. The radiation-driven role of Guangzhou as a core city has not yet fully covered the entire GBA, and there are obvious regional barriers and insufficient linkage in Chinese patent medicine patent cooperation among cities within the GBA. Combined with the QAP regression results, geographical proximity has a significant positive impact on collaboration, further confirming that cross-regional and cross-border collaboration is relatively difficult, which will constrain the balanced development of the overall regional innovation network in the long run.

5.3 Positive but Limited Effect of Technological Proximity, with Room for Improvement in Technological Synergy

The QAP regression results show that technological proximity has a significant positive impact on Chinese patent medicine patent cooperation in the GBA. Applicants with similar technological structures and high IPC classification overlap share similar

R&D directions and technical paths, making patent cooperation easier to form. However, in terms of effect intensity, the standardized coefficient of technological proximity is 0.022, far lower than 0.069 for geographical proximity, with weaker explanatory power for patent cooperation. This indicates that technological similarity plays a limited role in driving patent cooperation and cannot be regarded as the core driving factor for Chinese patent medicine patent cooperation in the GBA. Currently, there may still be technological barriers between regional applicants, with distinctive or differentiated technological R&D across enterprises, universities, research institutions and government agencies. Against the background of large volume but generally low quality, few high-value patents and insufficient core key technologies in China's Chinese patent medicine patent applications [22], innovation actors may have relatively high technological homogeneity, and technological complementarity and barriers have not yet become key drivers of collaboration.

6 Policy Implications

6.1 Building a Full-Chain Patent Cooperation Network and Strengthening the Hub Role of Core Actors

The high fragmentation of the network requires strengthening the linkage intensity between nodes. Guided by policies such as the *Implementation Plan for High-Quality Development of the Traditional Chinese Medicine Industry (2026–2030)*, the hub role of core applicants should be strengthened, and a multi-stakeholder patent cooperation network integrating industry, academia, medical institutions and government should be established. The government should build a public service platform for Chinese patent medicine patent cooperation, with Guangzhou as the centre, linking secondary-tier cities such as Shenzhen, Foshan and Zhongshan, and gradually expanding to Hong Kong, Macao and peripheral cities in Guangdong, so as to alleviate the development imbalance caused by the core-periphery structure. Drawing on the full-industry-chain collaboration experience of Japan's Tsumura & Co.[52] leading enterprises should play a leading role, joining hands with top universities and authoritative research institutions to establish long-term stable collaboration mechanisms, and promoting the transition from short-term scattered cooperation to a systematic and large-scale collaboration system. In addition, industry associations of traditional Chinese medicine should take

the lead in matching R&D resources of universities and research institutions with the industrialisation needs of enterprises, to improve the industry-university-research collaborative innovation model.

6.2 Optimising Spatial Layout and Deepening Cross-Regional and Cross-Border Coordination

As the core hub of the patent cooperation network, Guangzhou should give full play to its radiation-driven role. Meanwhile, to prevent excessive concentration of resources, efforts should be made to promote resource diffusion to the secondary tier of Shenzhen, Foshan, Zhuhai, Jiangmen and Zhongshan, and increase policy support and financial investment in peripheral cities such as Dongguan, Zhaoqing, Hong Kong, Macao and Huizhou. First, distinctive Chinese patent medicine industrial parks with remarkable scale benefits and strong radiation effects should be established to enhance the influence and development potential of the sector. A regional Chinese patent medicine patent database should be built to expand resource sharing and lower the threshold for patent cooperation. Second, the government may introduce special incentive policies for cross-border collaboration, such as fee reductions or special subsidies for Chinese patent medicine patents jointly filed by inland and Hong Kong/Macao applicants, to stimulate the enthusiasm of Hong Kong and Macao applicants for participation.

6.3 Strengthening Technological Collaborative Innovation and Cultivating High-Value Patents

First, support for the “Lingnan Traditional Chinese Medicine Modernisation” special programme should be enhanced. Through key technological breakthroughs and high-value technology cultivation, technological barriers should be leveraged to drive patent cooperation, so that technological proximity gradually becomes a core driving factor for the collaborative development of Chinese patent medicine patents. Second, drawing on South Korea’s experience in integrating traditional medicine with modern industries, the cross-integration of Chinese patent medicines with diverse industries such as general health, cosmetics and cultural tourism should be promoted, expanding the practical application scenarios of patents [53] [54]. Market demand should guide high-quality patent R&D and the cultivation of high-value Chinese patent medicines.

Meanwhile, core universities and leading enterprises should play their hub role, driving small and medium-sized enterprises and actors in peripheral regions to join the collaboration network through resource sharing. Small and medium-sized enterprises, in turn, should expand cooperation channels through industry-university-research collaboration, to promote long-term stability and innovative development of the collaboration network.

7 Research Limitations and Future Prospects

This study has certain limitations. First, the study focuses on the period from 22 February 2016 to 31 December 2024, with data retrieved in February 2026. In accordance with the 18-month publication lag of invention patent applications for invention patent applications, the latest patents from this period have not yet been published, so the full picture of patent cooperation in 2024 may not be captured. Second, the study mainly examines proximity from geographical and technological dimensions, and does not incorporate exogenous variables such as the GBA's policy environment and market demand for Chinese patent medicines, resulting in limited explanatory dimensions of influencing factors.

Future research can reduce the impact of time lags or extend the time span of data, adjust the measurement method of technological proximity, and incorporate multi-dimensional factors such as policy proximity and market demand proximity for further testing.

References

[1] Zhang, Y. F., Jin, W. W., Xu, Y., et al. (2025). Spatial characteristics of patent cooperation in China from the perspective of technological complexity [in Chinese]. *Scientia Geographica Sinica*, 45(12), 2563–2573.

[2] Xie, Z. T., Kong, F. C., & Xie, N. (2021). Spatiotemporal evolution of collaborative innovation among "Double First-Class" universities in the Yangtze River Delta: A social network analysis based on granted cooperative patents [in Chinese]. *R&D Management*, 33(5), 149–160.

[3] Xu, M., & Wang, H. M. (2018). Structure of university-enterprise patent cooperation network based on social network analysis: Inter-provincial comparison of universities in Yangtze River Delta urban agglomeration [in Chinese]. *Science and Technology Management Research*, 38(24), 87–95.

[4] Zeng, L., & Li, X. (2023). Spatiotemporal evolution and characteristics of industry-university-research patent cooperation network of universities in Chengdu-Chongqing economic circle [in Chinese]. *Science and Technology Management Research*, 43(16), 132–145.

[5] Tang, H., Gao, L. Z., & Liu, G. F. (2017). Spatiotemporal evolution of industry-university-research patent cooperation network in Beijing-Tianjin-Hebei region [in Chinese]. *Journal of Intelligence*, 36(10), 130–136.

[6] Li, S. X., Chu, S. Z., Yang, Q., et al. (2021). Evolution of industry-university-research patent cooperation network of biomedical industry in Jiangsu Province [in Chinese]. *Science and Technology Management Research*, 41(14), 73–80.

[7] Zhang, R. F., Zhao, Z. Q., & An, M. Y. (2021). Network structure and link prediction of patent cooperation applications in the Guangdong-Hong Kong-Macao Greater Bay Area [in Chinese]. *China Invention & Patent*, 18(03), 26–33.

[8] Zhong, Y., Ye, Y. H., & Wei, Y. H. (2020). Characteristics and influencing factors of urban network based on innovation connections: A case study of Guangdong-Hong Kong-Macao region [in Chinese]. *Science and Technology Management Research*, 40(7), 1–9.

[9] Chen, J. Y., Ma, L. Y., Tao, Q. Y., et al. (2020). Structural characteristics of patent cooperation network in China's chip industry [in Chinese]. *Science and Technology Management Research*, 40(8), 102–111.

[10] Wen, F. F. (2012). Econometric research on patent cooperation modes [in Chinese] [Doctoral dissertation]. Wuhan University.

[11] Gao, X., & Chen, K. H. (2015). Complex network analysis on evolutionary characteristics of cooperative innovation network structure [in Chinese]. *Science Research Management*, 36(6), 28–36.

[12] Zhang, W. J., Zhu, Q., & Liu, Y. X. (2025). Impact of university-enterprise cooperative R&D on patent innovation quality: Empirical research based on patent data of national "Little Giant" enterprises [in Chinese]. *Journal of East China Normal University (Educational Sciences)*, 43(11), 13–23.

[13] Xu, H. H., Li, S. X., Liu, J. Y., et al. (2023). Impact of enterprise network position on innovation performance from the perspective of cooperation network: A case study of pharmaceutical manufacturing industry [in Chinese]. *Science and Technology Management Research*, 43(22), 143–154.

[14] Yu, Q., Bai, M. P., & Qin, Y. D. (2018). Can multi-dimensional proximity promote cooperative innovation of new energy vehicle enterprises in China? [in Chinese]. *R&D Management*, 30(6), 67–74.

[15] Xi, Q. M., Li, G. P., Sun, Y. K., et al. (2022). Evolution characteristics and influencing factors of Beijing-Tianjin-Hebei scientific and technological cooperation network [in Chinese]. *Acta Geographica Sinica*, 77(6), 1359–1373.

[16] Veugelers, R., & Cassiman, B. (2005). R&D cooperation between firms and universities: Some empirical evidence from Belgian manufacturing. *International Journal of Industrial Organization*, 23(5–6), 355–379.

[17] Li, Y. N., Wang, B., Zhang, Y. Z., et al. (2018). Structural characteristics and evolution of university-enterprise patent cooperation network: A case study of "985 Project" universities [in Chinese]. *Science Research Management*, 39(3), 132–140.

[18] Zhang, L. Q., & Weng, Q. G. (2020). Research on industry-university-research collaborative innovation mechanism of government-university-enterprise trinity: Based on survey data of Fuzhou in recent years [in Chinese]. *Chinese University Science & Technology*, (9), 67–70.

[19] Yang, X. J., & Xiao, S. Y. (2012). Regional development of traditional Chinese medicine compound patents based on cluster analysis [in Chinese]. *China Journal of Chinese Materi a Medica*, 37(16), 2472–2477.

[20] Li, B., & Chen, X. D. (2015). Cooperative innovation of traditional Chinese medicine in China based on patent cooperation network [in Chinese]. *China Journal of Chinese Materi a Medica*, 40(6), 1212–1218.

[21] He, J., Feng, X. F., & Yuan, H. M. (2018). Evolution of industry-university-research collab orative innovation in traditional Chinese medicine based on patent data [in Chinese]. *Chine se Traditional and Herbal Drugs*, 49(01), 256–261.

[22] Zhen, S. Y. (2023). Construction of patent value evaluation model and cultivation strategy of high-value patents for Chinese patent medicines [in Chinese] [Doctoral dissertation]. Chi na Academy of Chinese Medical Sciences.

[23] Tang, S. L., Liu, M. X., Qian, Y. X., et al. (2022). Characteristics of medical industry-uni versity-research cooperation network in East China based on patent data [in Chinese]. *Scie nce and Technology Management Research*, 42(16), 85–92.

[24] Xu, H. C., Feng, Z. P., Zhao, M. C., et al. (2023). Evolution of innovation network of tra ditional Chinese medicine industry in Yangtze River Delta from patent perspective [in Chin ese]. *Journal of Nanjing University of Chinese Medicine (Social Science)*, 24(02), 116–122.

[25] Zhi, X. J. (2021). Analysis and reflection on traditional Chinese medicine patents in the G uangdong-Hong Kong-Macao Greater Bay Area [in Chinese]. *Chinese Journal of Library a nd Information Science for Traditional Chinese Medicine*, 45(06), 18–22.

[26] Chen, C. R., Zhang, G. Y., Hong, H. D., et al. (2022). Current situation and suggestions o f traditional Chinese medicine patent layout in the Guangdong-Hong Kong-Macao Greater Bay Area [in Chinese]. *Chinese Journal of New Drugs*, 31(14), 1350–1358.

[27] Pan, J., & Zhang, W. L. (2022). Evaluation and promotion path of scientific and technolog ical innovation efficiency of traditional Chinese medicine in Guangdong: Based on the bac kground of building a TCM innovation highland in the Greater Bay Area [in Chinese]. *Sci ence and Technology Management Research*, 42(13), 59–65.

[28] Huang, Z. Y., Zhang, W. L., & Shu, Y. (2025). Construction efficiency and spatial autocor relation analysis of the internationalization highland of traditional Chinese medicine in the Guangdong-Hong Kong-Macao Greater Bay Area [in Chinese]. *China Medical Herald*, 22(1 6), 159–162.

[29] Li, G. P., & Wang, C. Y. (2012). Spatial characteristics and spatiotemporal evolution of pr ovincial innovation output in China: An empirical study based on exploratory spatial data analysis [in Chinese]. *Geographical Research*, 31(01), 95–106.

[30] Xia, L. J., Xie, F. J., & Wang, H. H. (2017). Institutional proximity, technological proximi ty and university-industry collaborative innovation performance: Based on joint patent data [in Chinese]. *Studies in Science of Science*, 35(05), 782–791.

[31] Petruzzelli, A. M. (2011). The impact of technological relatedness, prior ties, and geographi cal distance on university–industry collaborations: A joint-patent analysis. *Technovation*, 31 (7), 309–319.

[32] Cao, M. D. (2019). Research on competitiveness and development countermeasures of Chin a's Chinese patent medicine industry based on the "Diamond" model [in Chinese] [Master' s thesis]. Chengdu University of Traditional Chinese Medicine.

[33] Li, X. K., Zhang, Y. S., & Xiao, G. L. (2019). University-industry cooperation network and academic performance of universities: Empirical evidence from Tsinghua University [in Chinese]. *Soft Science*, 33(1), 1–5.

[34] Liu, J. (2004). *Introduction to social network analysis* [in Chinese]. Social Sciences Academic Press.

[35] Scott, J. (2007). *Social network analysis* (J. Liu, Trans.) [in Chinese]. Chongqing University Press. (Original work published 2000).

[36] Luo, J. D. (2010). *Lectures on social network analysis* [in Chinese]. Social Sciences Academic Press.

[37] Luce, R. (1950). Connectivity and generalized n-cliques in sociometric group structure. *Psychometrika*, 15, 169–190.

[38] Bron, C., & Kerbosch, J. (1973). Finding all n-cliques of an undirected graph. *Communications of the ACM*, 16, 575–577.

[39] Seidman, S., & Foster, B. (1978). A graph theoretic generalization of the clique concept. *Journal of Mathematical Sociology*, 6, 139–154.

[40] Seidman, S., & Foster, B. (1978). A note on the potential for genuine cross-fertilization between anthropology and mathematics. *Social Networks*, 1, 65–72.

[41] Seidman, S. (1983). Network structure and minimum degree. *Social Networks*, 5, 269–287.

[42] Borgatti, S. P., & Everett, M. G. (1999). Models of core/periphery structures. *Social Networks*, 21(4), 375–395.

[43] Newman, M. E. J., & Girvan, M. (2004). Finding and evaluating community structure in networks. *Physical Review E*, 69(2), 026113.

[44] Newman, M. E. J. (2006). Modularity and community structure in networks. *Proceedings of the National Academy of Sciences*, 103(23), 8577–8582.

[45] Blondel, V. D., Guillaume, J. L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment*, 2008(10), P1000.

[46] World Intellectual Property Organization. (2017). *International Patent Classification (IPC) 2017.01: A23L Foods, foodstuffs, or non-alcoholic beverages*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20170101/transformations/ipc/20170101/en/htm/A23L.htm

[47] World Intellectual Property Organization. (2019). *International Patent Classification (IPC) 2019.01: A23K Feeding-stuffs specially adapted for animals*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20190101/transformations/ipc/20190101/en/htm/A23K.htm

[48] World Intellectual Property Organization. (2017). *International Patent Classification (IPC) 2017.01: A61K Preparations for medical, dental, or toilet purposes*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20170101/transformations/ipc/20170101/en/htm/A61K.htm

[49] World Intellectual Property Organization. (2018). *International Patent Classification (IPC) 2018.01: A61P Specific therapeutic activity of chemical compounds or medicinal preparations*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20180101/transformations/ipc/20180101/en/htm/A61P.htm#145

[50] World Intellectual Property Organization. (2023). *International Patent Classification (IPC) 2023.01: A61Q Specific use of cosmetics or similar toiletry preparations*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20230101/transformations/ipc/20230101/en/htm/A61Q.htm.

[51] World Intellectual Property Organization. (2017). *International Patent Classification (IPC) 2017.01: C12R Indexing scheme associated with subclasses C12C–C12Q, relating to microorganisms*. https://www.wipo.int/classifications/ipc/en/ITsupport/Version20170101/transformations/ipc/20170101/en/htm/C12R.htm

[52] Wang, T. R., Liu, P., Hou, Y. Y., et al. (2024). Patent layout analysis of Japanese Kampo medicine enterprises: A case study of Tsumura & Co. [in Chinese]. *Central South Pharmacy*, 22(05), 1365–1371.

[53] Ren, H., & Liu, M. J. (2016). Research on the legal system of Korean traditional medicine cultivation [in Chinese]. *Journal of East China University of Science and Technology (Social Science Edition)*, 31(05), 52–58+78.

[54] Huang, H. Y., & Zhou, Y. D. (2025). Analysis and enlightenment of the development of traditional Korean medicine industry [in Chinese]. *Industrial & Science Tribune*, 24(05), 17–19.

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